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Preparing Commercial Space For Safety Management System Implementation

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PREPARING COMMERCIAL SPACE COMPANIES FOR SAFETY MANAGEMENT SYSTEM IMPLEMENTATION

by

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Brian Teske,
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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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ABSTRACT

In 2014 The commercial space company, Scaled Composites, suffered a catastrophic event during a test flight, killing one astronaut. Several recommendations for the Federal Aviation Administration, Office of Commercial Space Transportation emerged from the National Transportation Safety Board. One recommendation was the introduction of a safety management system (SMS) as a safety protocol and became the genesis of this research project. This study has two purposes. The first purpose is to investigate whether the attributes of safety management system theory (SMST) exist in commercial space organizations. The second purpose is to explore the characteristics of high reliability theory (HRT) to determine whether they occur in SMS organizations in the airline industry. The attributes of HRT exist in some high-risk organizations.

An exploratory, sequential, mixed-method study was performed using grounded theory and the Delphi methodology. A survey, the Organizational Safety Attribute Awareness Survey, was developed, combining the SMS theory-based survey with the HRT questions used in this study. Two demographic questions were used to determine whether one's role in the organization or the length of time in the industry impacted perceptions of SMS and HRT attributes.

Structural modeling produced an acceptable SMS survey model. Independent *t*-test results between commercial space and airline participants show promising acceptance levels for three of the four SMST elements. Results showed that participants from the commercial space organization had higher mean values for the attributes of SMST. Further, results suggested similar outcomes with the characteristics of HRT in participants from the airline industry. The practical implications of this research are twofold. First, understanding the degree of organizational members' awareness of SMS attributes will allow for the focused implementation of the program with resources targeted to areas that require more attention. Second, by highlighting the recognition of HRT in an SMS environment, current safety awareness may be enhanced and include additional safety tools aimed at increasing overall organizational safety.

Keywords: airline, commercial space, high reliability theory, mindfulness, safety management system, safety management system theory, safety culture.

ACRONYMS

ANOVA	analysis of variance
AST	Office of Commercial Space Transportation
AVE	average variance extracted
BCa	bias corrected accelerated
CFA	confirmatory factor analysis
CFI	comparative fit index
CI	confidence interval
CR	composite reliability
CSLCA	Commercial Space Launch Competitiveness Act of 1984
ESMM	exploratory, sequential, mixed-methods
FAA	Federal Aviation Administration
GT	grounded theory
HRO	high-reliability organization
HRT	high-reliability theory
ICAO	International Civil Aviation Organization
IRB	institutional review board
ISS	International Space Station
MM	measurement model
NASA	National Aeronautics and Space Administration
NAT	normal-accident theory
NTSB	National Transportation Safety Board
PA	path analysis
RMSEA	root mean square error of approximation
SEM	structural equation modeling
SME	subject-matter expert
SMS	safety-management system
SMST	safety-management-system theory
SOS	Safety Organizing Scale
SpaceX	Space Exploration Technologies Corporation
SRM	safety-risk management
TLI	Tucker–Lewis Index

CHAPTER 1

INTRODUCTION

The health and safety of the general public during private commercial space operations is a top priority for the Federal Aviation Administration, Office of Commercial Space Transportation (FAA/AST). The FAA/AST also protects property and national-security interests, and encourages the private commercial space industry (FAA, 2015a, p. 3). The FAA/AST works in concert with individual commercial space companies to formulate safety guidelines, identify safety risks, and codify standard practices for the industry. A key to future safety theory adoption may include understanding the degree to which organizational members recognize safety attributes. This information may help the industry adopt necessary adjustments to existing safety protocols.

Space flight is inherently complex and risky, with little room for error. When discussing the potential of the FAA/AST implementation of a safety management system (SMS), Zee and Murray (2009) stated that "the future of the commercial human space flight industry will depend on its ability to continually improve its safety performance" (p. 5). During the last decade, few space-related accidents have occurred. Maintaining a high level of coordination between the FAA/AST and space companies will become more of a requirement to advance safety (FAA, 2015a; Zee & Murray, 2009). One possible future initiative may include the development of a universal commercial space SMS, the details of which were included in the 2015 FAA/AST *Safety Management System Manual*.

In 2014, SpaceShipTwo, operated by Scaled Composites, suffered a catastrophic inflight breakup during a test flight (National Transportation Safety Board [NTSB], 2015). The NTSB was tasked with an investigation and released their findings after its completion. Implementing an SMS was one recommendation.

Seeing the success of the SMS and its various components in airlines, the FAA/AST formulated one type of safety program for space companies (FAA, 2015a). The latest version of their SMS document, edited in 2015, sets the foundation for private commercial space companies regarding safety culture (FAA, 2015a). Although not mandatory, an SMS program may become commonplace as more humans begin traveling into space.

Wakimoto (2019) suggested that the International Civil Aviation Organization (ICAO), along with other agencies, create a set of international safety standards for commercial space companies. Today, private commercial space companies have different vehicles, use proprietary launch/recovery procedures, use different fuel blends, and have specific orbital requirements predicated on operational necessities as the launch vehicles transition through the National Air Space (FAA, 2015a; Hays, Chu, & Llanos, 2019). Establishing uniformity of safety measures may be challenging for the FAA/AST to achieve until they begin to regulate the industry. However, common best practices and standard safety protocols are necessary (Chatzipanagiotis & Kyriakopoulos, 2019). Achieving safety uniformity will be a task the FAA/AST will need to develop and enforce in the future (FAA, 2015a; Zee & Murray, 2009). The public's perception of safety in commercial space travel is dictated by the overall levels of safety of space flights. Space tourism will increase the public's awareness when these flights become routine, thereby increasing total space operations (Canis, 2016; Dickson, 2020; Whitesides, 2019).

The FAA/AST is required to "encourage, facilitate, and promote US commercial space transportation" (FAA, 2015a, p. 1). The FAA/AST accomplishes these tasks through tight controls of risks to the sector. Figure 1 depicts a triangulation of risks used by the FAA/AST to illustrate a risk-management-mitigation model for public safety.

Figure 1. Key elements of risk.
Note. From *Safety Management System for Domestic, Flag, and Supplemental Operations Certificate Holders; Final Rule,* by Federal Aviation Administration, 2015a, Washington, DC, US: U.S. Government Printing Office.

Private Commercial Space

To better understand the need for a universal SMS protocol requires an examination of the various aspects of the private commercial space industry. The following areas include topics of government-policy changes, private commercial space launches and recoveries, delivery of satellites into orbit, and supply missions to the International Space Station (ISS). The space-tourism sector is included in this discussion, given its potential for prodigious growth (Chang, 2015; Chang & Chern, 2016; Loizou, 2006).

The development of the commercial space sector as a launch provider resulted from changes in federal policy (Canis, 2016; Chang, 2015; Kay, 1998).The passing of the Commercial Space Launch Competitiveness Act of 1984 (CSLCA) encouraged space operations and associated services by private-sector commercial space companies. The Act states that "the United States should encourage private sector launches, reentries, and associated services and, only to the extent necessary, regulate those launches, reentries, and services to ensure compliance with international obligations of the United States" (CSLCA, 1984, p. 1.). The Act also began the advancement of a public–private partnership between the government and the private commercial space industry (George, 2019). The CSLCA was amended in 2004 and 2015 (CSLCA 2004, 2015) extending the length of time in which selected FAA/AST regulation nonenforcement was to occur (Canis, 2016). By not regulating commercial space, companies have additional time for innovations (Chatzipanagiotis & Kyriakopoulos, 2019). This buffer allowed for augmentation of needed technology and a development period for the industry (Canis, 2016). Necessary advancements with flights into orbit, including human space travel, continued (Canis, 2016; M. S. Smith, 2011).

A shift toward an emphasis on private commercial space operations began in earnest during the presidency of Barack Obama. One of these policy adjustments included an increased dependence on the private commercial space industry's development through government augmentation of a commercial-crew space-transportation system aimed at carrying astronauts to and from low earth orbit (M. S. Smith, 2011). These adjustments allowed NASA to focus on sending astronauts and equipment to destinations beyond the earth's orbit. Congress made further adjustments to the proposed Obama space-policy changes, in part by crafting the National Aeronautics and Space Administration (NASA) Authorization Act of 2010. The Act stated, in part, that the FAA administrator would develop strategies necessary to anticipate the needs of commercial space companies and offer any assistance needed to help augment the development of commercial space operations (NASA Authorization Act of 2010).

Furthermore, the signing of the U.S. CSLCA of 2015 cultivated further changes in government space policy (Dodge, 2016). These changes aimed to strengthen or adjust the industry, along with parallel changes to government policy. During this time, Space Exploration Technologies Corporation (SpaceX) won a multiyear contract to perform launches for NASA (Jones, 2018; Ma, Xie, Liu, & Wu, 2019; M. S. Smith, 2011). Obama juxtaposed the immense opportunities of a space economy with the dire financial circumstances of the time, thus the shift to a public–private partnership (M. S. Smith, 2011). Some in government were caught off guard and questioned whether the private sector would be up to the task of space operations. Ultimately, Congress voted to compel NASA to complete work on a new space-crew transportation system, as well as continue to support the commercial space industry (M. S. Smith, 2011).

Commercial space companies have collaborated with NASA to augment space flights beginning in the 1950s (Dodge, 2016; Chatzipanagiotis & Kyriakopoulos, 2019). The increased growth was labeled “new space” and grew during the Bush and Obama presidencies (Denis et al., 2020). The economic decline following the financial recession in the early 2000s shifted the governmental focus toward fostering a vibrant private commercial space industry. The changes to the NASA budget resulted in the number of successful commercial space companies seen today. Forward-thinking presidents have helped set in place and foster the seeds of commercial space (Morring, 2009). NASA was once aided by a few commercial space companies and now are the aid for the private companies (Denis et al., 2020). Launches today are monthly rather than annual events and are predicted to continue (Chang, 2015).

The increase in the use of commercial space companies by NASA dates back to the 1980s when President Ronald Reagan began to explore the notion of commercial ventures helping NASA with space flights (Kay, 1998). Each president has advanced the growth of the commercial sector. President Obama funded the most amount of money, which spurred a rapid acceleration in commercial space growth (Obama, 2010; M. S. Smith, 2011). In 2014, NASA announced the concept of Launch America or commercial space taxi services as the next chapter in human spaceflight (Chang, 2015; M. S. Smith, 2011). Chang (2015) further stated that NASA had invested billions of dollars into companies such as Boeing and SpaceX, tasked with resupply missions to the ISS. The ultimate goal of launching humans back into space from the United States' soil (Chang, 2015). Figure 2 highlights a timeline of significant space accomplishments.

The number of commercial space companies that research, design, and operate their space vehicles for profit has grown in the last several years. These companies include launches into suborbit, launches to low earth orbit, mission to resupply the ISS, placing satellites into orbit, and soon, crewed flights to the Moon and beyond (Reddy, Nica, & Wilkes, 2012). The sector of space tourism alone has the potential to be a $700 million market annually (Chen & Chen, 2014). In 2008, Astrium's Chief Technology Officer Laine affirmed that public interest might create enough demand to exceed the Futron Corporation's space-tourism market (Beard & Starzyk, 2002). The Futron

Corporation's space-tourism-market study in 2002 was one of the first forecasts highlighting the potential of the commercial space-industry sector, with projected growth in the industry (Beard & Starzyk, 2002). The commercial space industry was estimated to become a multibillion industry by 2021 (Chang, 2015; Chang & Chern, 2018; Loizou, 2006). In passing the NASA Transition Authorization Act of 2017, Congress signaled a growing interest in space flight by the private commercial space industry to the ISS. This act expanded the role of commercial space-operations support. It included the development of reliable ISS resupply-mission capabilities as well as transporting crew members into space, ending reliance on the Russian space program to accomplish these tasks. (NASA Transition Authorization Act, 2017).

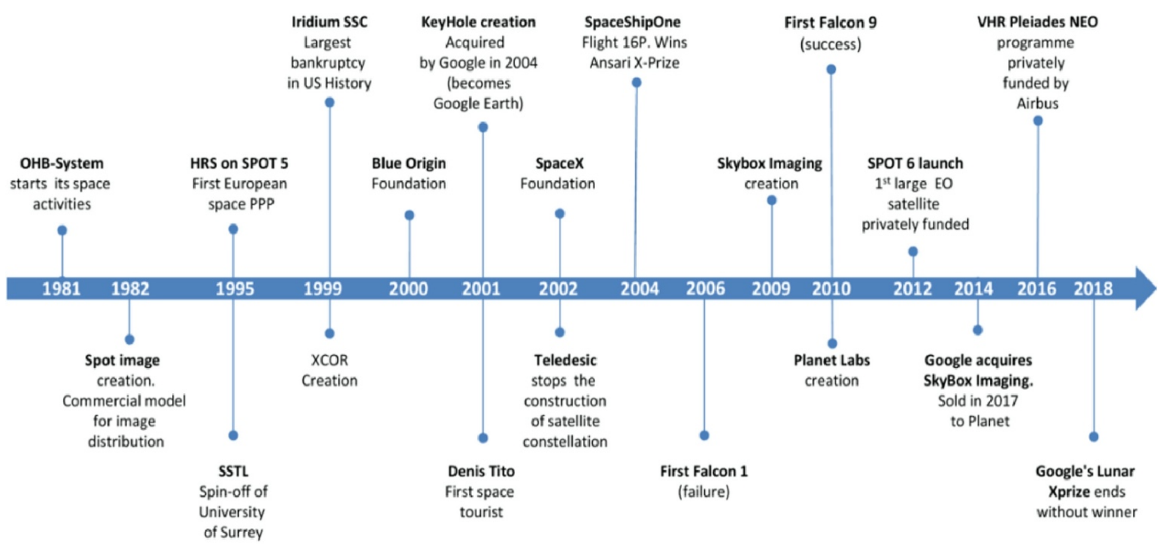


Figure 2. Innovations in space.
Note. Adapted from New Space to Big Space: How Commercial Space Dream is Becoming a Reality, by G. Denis et al., *Acta Astronautica, 166,* 431–443. https://doi.org /10.1016/j.actaastro.2019.08.031

Historically, government-run space programs were the only means of flight into space. Today, SpaceX, Blue Origin, Bigelow, Virgin Galactic, ULA, and many more companies are vying for market share in the space-flight sector (Chandler, 2007; Chang, 2015; Chang & Chern, 2018). The new terms “NewSpace,” “alt.space,” and “entrepreneurial space” describe the newer entrants into space technology and travel (Denis et al., 2020; Martin, 2014). These descriptive labels include the actual commercial space organizations that conduct the launches (Davidian, 2019). Table 1 depicts the types of space activities in the commercial space industry.

Table 1

Private Commercial Space Opportunities

Orbital Commercial Space Possibilities	
Tourist industry	Low earth orbit (LEO) (between 180–3000 km)
	High earth orbit (HEO)–Geocentric 35,786 km
	Short weightlessness flights
	Space Adventures: private citizens to ISS
Research/Applications	Conduct experiments continuously in the orbital environment (microgravity and life sciences)
	Launch small satellites from ISS
Satellite servicing	Launch small satellites from ISS
	Satellites, put them in proper orbits, refuel, fix, and upgrade systems
Deep Space Commercial Space Opportunities	
Tourist/Explorers	The Inspiration Mars Foundation
	Flights to the Moon
Space research	Human Factors: to be productive and happy in deep space flight; in-space economy
Mining and resource Use	Asteroid mining
Servicing a space-based economy and settlements	3D printing in space, metal & materials processing, and building materials
	Space manufacturing

Note. ISS = International Space Station, adapted from *NewSpace: The emerging commercial space industry,* by G. Martin, 2014, Albuquerque, NM, US: National Aeronautics and Space Administration

Satellites

The manufacturing cost of producing satellites has decreased in the last decade, as well as the costs of launching them into space (Canis, 2016; Denis et al., 2020). The lower costs needed to place a satellite into space resulted in a growth in the market (Canis, 2016). The NASA Transition Authorization Act (2017) described satellite commerce as launching those used for communication, earth observation, global atmospheric monitoring, transportation, and safety enhancement. In 2015, global satellite manufacturing revenues were $6 billion (Canis, 2016). Recent congressional acts have offered insulation to commercial space companies often applied to other budding industries by federal regulations (Canis, 2016). The Commercial Space Launch Amendment Act of 2004 lowered the barriers of entry into the market. This Act resulted in an increased number of satellite developers, encouraged by cheaper manufacturing costs and prices to launch devices into space.

Advancements in satellite technology allow them to be made much smaller than previous satellites. Cube-structured satellites, or smaller weight satellites, comprise 126 of a total of 262 satellites launched in 2015. These satellites are an industry standardized size and weigh under 22 pounds each (Canis, 2016). The design gives uniformity among manufactures and also allows the satellites to ride on existing rocket launches, thereby opening the market to new companies by lowering barriers to entry (Sweeting, 2018). The success of SpaceX's Falcon 9 launches had shown economic viability with reusable rockets, which, coupled with cheaper manufacturing costs, results in putting a satellite into space more efficiently feasible today (Denis et al., 2020).

Supply Missions

SpaceX won a NASA contract to resupply materials to the ISS (Ma et al., 2019; M. S. Smith, 2011). Historically, the high cost to launch a kilogram into space was the limiting factor for space companies (Jones, 2018). SpaceX solved that issue with an economical reusable rocket manufactured inhouse, eliminating the need for outside contractors (Drenthe, Zandbergen, Curran, & Van Pelt, 2019). Although Blue Origin was the first company to have a reusable rocket (Chang, 2015), SpaceX was the first commercial space company to capitalize publicly on the business model and has made space flight profitable (Jones, 2018; Ma et al., 2019).

SpaceX began a supply mission contract with NASA in 2012 (Jones, 2018). The savings derived from the use of reusable rocketry technology drove the cost to launch a kilogram into space down to a profitable level (Denis et al., 2020; Jones, 2019). Figure 3 shows the reduction in costs to send a kilogram of material into space achieved by technological advancements using reusable rockets. The introduction of SpaceX's Falcon 9, in addition to the use of the Dragon autonomous cargo ship, reduced the space shuttle cost to ISS by approximately a factor of four (Jones, 2018).

Space Tourism

In 2004, Scaled Composites, with Mike Melvill flying the space vehicle, became the first commercial space company to fly into space with a reusable craft called SpaceShipOne and won the Ansari X-prize (Chang 2015). This flight ushered in the concept of new space tourism. Space tourism started a decade ago with flights to the ISS, and a total of seven tourists made the journey (Chang 2015). Tentatively scheduled space tourism launches for Virgin Galactic and Blue Origin are reported to begin in 2020.

Virgin Galactic will launch from the Spaceport American in Truth or Consequences, New Mexico (Sammler & Lynch, 2019), and Blue Origin will launch from West Texas (David, 2005; Davidian, 2019). For the space-tourism sector to experience the fruition of the marketplace cycles, necessary safety improvements resulting in safety levels at least equal to the levels of early commercial aviation are required (Loizou, 2006).

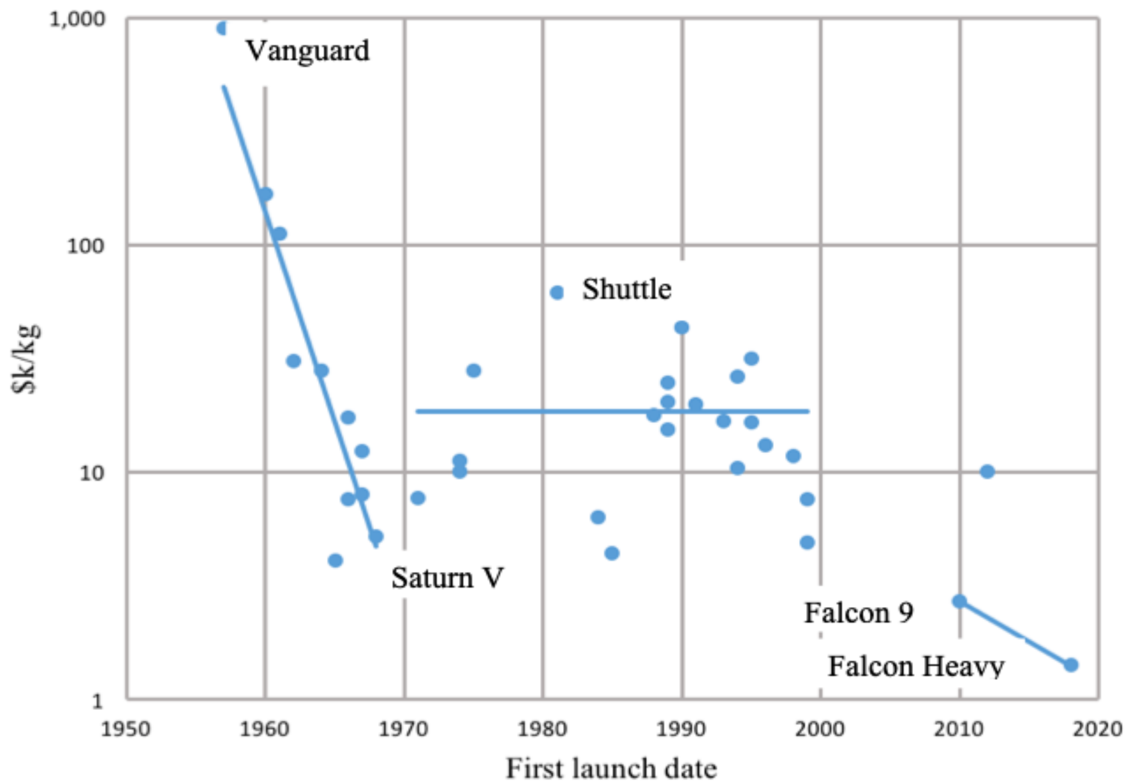


Figure 3. Changes in launch cost per kilogram to low earth orbit.
Note: From *The Recent Large Reduction in Space Launch Cost,* by H. Jones, 2018, Paper presented at the 48th International Conference on Environmental Systems. Albuquerque, NM, US: National Aeronautics and Space Administration.

Purpose for the Study

The purposes of this exploratory, sequential, mixed-methods (ESMM) study were to identify a method to introduce an SMS program to commercial space organizations and to explore the presence of high-reliability theory (HRT) attributes in companies with an existing SMS. An SMST attribute-based survey instrument was designed and tested to uncover any underlying recognition of the elements. A comparison between SMS responders and non-SMS responders allowed the attributes of safety management system theory (SMST) to be measured in the commercial space industry.

The first objective of the study was to develop a means to ascertain whether the attributes of SMS exist in commercial space organizations. The existence of SMST attributes may allow commercial space companies a more expedited means of implementing an SMS. The second objective was to assess the presence of the SMST in commercial space companies to validate the survey and to create benchmark values for future commercial space-organization testing. The third was to examine HRT attributes in an SMS environment. HRT attributes are a well-established group of safety-related traits that reside among the members of some successful high-risk organizations with very few accidents. Recently researchers have focused on the means of adopting these attributes in the existing safety culture (e.g., in the medical field; Vogus & Sutcliffe, 2007). Developing a means to determine the existence of HRT traits may allow companies that use an SMS the ability to augment existing safety policies, thereby increasing the safety awareness of members and offering additional safety tools.

A new set of survey questions were required to test for SMST attributes to accomplish these tasks. The design of existing published SMS survey questions does not target revealing SMS attributes in organizations without an SMS. The final survey added two demographic questions to published HRT survey questions. Furthermore, the intended goals of this research were to expand the literature related to safety theory and practices in commercial space operations. Simultaneously, this research expands the theory of high reliability, specifically in organizations using an SMS as the formal protocol.

Operating in space remains a high-risk undertaking with a need for standard safety protocols among space organizations. Adopting a standardized SMS, as well as introducing additional safety concepts, may help the FAA/AST more efficiently enforce safety standards (FAA, 2015a). The feasibility of implementing a proven, holistic, and proactive safety program such as an SMS in companies might become more prevalent (Chen & Chen, 2012). Furthermore, augmenting operations with additional safety theories, such as HRT, may positively impact safety. Highlighting situations where HRT exists naturally in an SMS environment may offer companies opportunities to adopt additional safety initiatives without changing the underlying safety structure. Studies performed with SMS and HRT have implied a correlation between these two concepts during operations (Pariès, Macchi, Valot, & Deharvengt, 2018). This connection means that different theories may have overlapping influences on the safety culture of an organization. Measuring whether members embrace the concepts may help enhance the overall safety culture of an organization. Determining that attributes of SMST exist in organizations may help them implement an SMS more effectively. Showing the existence of any HRT traits offers possible means to augment existing safety protocols.

An SMS is a unique type of researched safety system that involves the entire organization as one, all following a standardized set of safety principals (Chen & Chen, 2012). This suggests that an SMS intertwines with a safety culture, integrated into the entire operation from top executives to new hires (Antonsen 2009). As a formal safety system, SMS is used internationally and provides a systematic safety approach for a formal, universal safety protocol (ICAO, 2013).

With an increase in private commercial space operations, the FAA/AST may introduce a formal standardized SMS structure for the industry (FAA, 2015a). The 2015 NTSB report on the crash of SpaceShipTwo by Scaled Composites encouraged the idea of adopting an SMS. The report concluded,

> "The NTSB is encouraged by the FAA/AST's progress in implementing SMS and believes that, if SMS principles are followed, they will be an effective means for enhancing the regulatory oversight of the commercial space industry. However, at the time of the evaluation of Scaled's experimental permit applications, FAA/AST management underutilized FAA/AST evaluators' expertise, even though they understood the risks associated with commercial space flight, because FAA/AST management appeared to be more concerned about ensuring that the FAA's authority in this emerging industry was not being exceeded beyond defined limits and maintaining the timeframe in which to approve experimental permit applications. Further, the filtering of questions and the lack of direct communication between FAA/AST technical staff and Scaled technical staff impeded Scaled's ability to take advantage of the FAA/AST's safety expertise." (NTSB, 2015, p. 60)

Although not in use currently, a standard SMS among private commercial space community members will allow the FAA/AST, as the government safety-oversight agency, to regulate the industry more effectively (Hale, 2003). Similar to the world's airline-safety structure, a standard safety strategy would provide the necessary agency tools to successfully maintain safety (Chatzipanagiotis & Kyriakopoulos, 2019).

HRT was introduced during the mid-1980s and continues to be of interest in multiple industries. High reliability organizations (HRO), or organizations operating without accidents in high-risk environments, exhibit HRT traits (Weick & Sutcliffe, 2015). Research on the expansion of organizations that exhibit HRT attributes grew to include the medical industry as well (Vogus & Sutcliffe, 2007).

The addition of SMS into commercial space will be a new approach to safety management. To date, no commercial space company has adopted the use of an SMS. Similarly, the introduction of HRT attributes into an airline with an active SMS may offer additional safety tools for the organization. The recognition of SMST or HRT may have a positive impact on an organization's overall safety levels.

The commercial space industry works diligently to operate safely. Given the nature of risky, repetitive operations, the chances of maintaining a high level of safety may prove challenging. A catastrophic event involving fatalities of space-crew members and the public on the ground would have a devastating impact on the entire space industry. Additionally, an accident may have an overwhelming economic outcome on the company, causing severe financial hardships. Today's commercial space industry encompasses all aspects of spacecraft design, manufacturing, and operations. The FAA/AST (2015a) SMS manual discusses the development of a formal SMS program for future implementation. SMS has proven to be a comprehensive, proactive safety method in aviation, medicine, and other industries around the world (Moorkamp, Kramer, van Gulijk, & Ale et al., 2014; Zee & Murray, 2009).

Problem Statement

The FAA/AST may find itself in the same position that the FAA did with the airlines, with the need for a universal, industrywide safety protocol. The commercial space industry is projected to expand rapidly (Dickson, 2020), aligned with the need for a consistent, formal safety protocol. The FAA/AST projects commercial space companies will seek more than 50 licenses for launch and recovery operations in 2020. Implementing a standardized SMS for the industry may become an essential aspect of maintaining high levels of safety by FAA/AST. In other industries, such as industrial or service sectors, companies using an SMS have shown positive effects through lower accident rates and improvements to the culture as a whole (Fernández-Muñiz, Montes-Peón, & Vázquez-Ordás, 2007). This trend may hold for commercial space as well.

Additionally, understanding whether high reliability attributes exist in an SMS environment may foster a positive safety culture and may prove to be a significant step forward. A group of researchers from the University of California, Berkeley, developed HRT in the 1980s (La Porte & Consolini, 1991; Sutcliffe, 2011). The principles of high reliability traditionally were used to describe HROs that were high-risk companies with limited numbers of accidents (La Porte & Consolini, 1991; Rijpma, 1997; Roberts, 1990). Therefore, it is conceivable that high reliability traits exist in the members working in an airline SMS structure (Dekker & Woods, 2009).

It is unclear whether commercial space companies will adopt the structure of SMS organically. Although each commercial space company has a safety program with an existing safety culture, adopting a formal SMS may require companies to make adjustments to their present safety structures (Moorkamp et al., 2014). It is also unclear whether the attributes of HRT can be determined to exist in the airline industry. Traditionally, HRT attributes are a means to describe an HRO whereas an SMS is operations based and measurable as a formal safety structure (Pariès et al., 2018).

Research Questions

Comparing responses from participants in organizations with an SMS to those in organizations without an SMS offered the opportunity for direct evaluations. Those working in an SMS environment were more likely to have stronger reactions to SMS questions. These results may offer a baseline for the comparison between the two groups. Additionally, comparisons of mean values from the responses for HRT attribute questions offer the opportunity to conclude levels of understanding and acceptance. Data accrued using identical surveys were sent to separate groups. The following research questions were tested during the quantitative phase of the study:

1. What is the validity and reliability of a measurement instrument that measures the overarching concept of SMS in aviation and commercial space organizations?
2. What are the differences in the mean responses of participants from commercial space organizations without an SMS and airlines with an SMS on factors underlying SMS?
3. What are the differences in the mean responses of participants from commercial space organizations without an SMS and airlines with an SMS on factors underlying HRT?

Hypotheses

A method of preparing commercial space for SMS implementation used in this research project was to determine whether any SMS attributes already existed in the industry. To date, no commercial space company uses an SMS as a formal safety protocol. This situation presented a challenge given that no SMS historical data were available for comparison in the industry. The method of testing underlying SMS attributes required developing, through the iterative grounded-theory process, lists of SMS attributes for questions on a survey instrument. These questions needed to capture the essence of the elements without using any of the standard SMS taxonomies. The survey instrument was the means to determine which SMS elements participants recognized. This study's prediction was that some underlying attributes of SMSs exist in organizations in the commercial space industry that do not have an SMS in place as their formal safety structure.

Additionally, the study entailed surveying for HRT attributes in an airline SMS environment. The Safety Organizing Scale, validated by Vogus and Sutcliffe (2007), was adopted for this research. The researcher predicted that some HRT attributes would exist organically in airline organizations having a fully functioning SMS safety protocol. HRT attributes are not concepts currently discussed in airline safety culture.

The following hypotheses were tested for the recognition of SMS attributes in commercial space operations. Comparing commercial space companies without SMS and airlines with SMS results allowed for an evaluation between participants. Baseline values helped determine areas of focus or reveal emphasis items for future testing in commercial space organizations.

- H_{0a} There is no difference in the mean value of items that measure safety policy among commercial space organizations without an SMS and airlines with an SMS.
- H_{0b} There is no difference in the mean value of items that measure safety-risk management (SRM) among commercial space organizations without an SMS and airlines with an SMS.
- H_{0c} There is no difference in the mean value of items that measure safety assurance among commercial space organizations without an SMS and airlines with an SMS.
- H_{0d} There is no difference in the mean value of items that measure safety promotion among commercial space organizations without an SMS and airlines with an SMS.

The following hypotheses determine the basic understanding or recognition of HRT attributes. Participants from both groups may not have been aware of the HRT traits. However, comparisons between the two groups offers evaluation of basic understandings of latent HRT.

- H_{0e} There is no difference in the mean value of items that measure preoccupation with failure among commercial space organizations without an SMS and airlines with an SMS.
- H_{0f} There is no difference in the mean value of items that measure the reluctance to simplify operations among commercial space organizations without an SMS and airlines with an SMS.

- H_{0g} There is no difference in the mean value of items that measure sensitivity to operations among commercial space organizations without an SMS and airlines with an SMS.
- H_{oh} There is no difference in the mean value of items that measure resilience in operations among commercial space organizations without an SMS and airlines with an SMS.
- H_{0i} There is no difference in the mean value of items that measure deference to expertise among commercial space organizations without an SMS and airlines with an SMS.

These hypotheses target determining any effects the two demographic questions of role and time in the industry may have on the recognition or understanding of SMS and HRT attributes.

- H_{0j}. There is no difference in the mean values of perception of SMST in the management role in the organization.
- H_{0k}. There is no difference in the mean values of perception of SMST in the length of time in the industry.
- H_{0l}. There is no difference in mean values of perception of HRT in the management role in the organization.
- H_{0m}. There is no difference in mean values of perception of HRT in length of time in the industry in the organization.

Research Limitations and Assumptions

For this research study, one assumption was that the final survey instrument applied to all high risk, complex, repetitive-operation organizations. An additional assumption was that the sample group represented the overall larger subject group. Efforts were made to include individuals who represented a diverse set of the most representative aspects of the two groups. Other assumptions included the following:

1. The groups consisted of qualified participants.
2. The sample group represented a general sample of the total population.
3. The study surveyed general companies with an SMS and commercial space organizations without an SMS.
4. Participants in the non-SMS group did not have experience with an SMS.
5. Participants took the survey once.

The researcher worked diligently to diminish the effects of any limitations that may have skewed the results. The limitations of this study included the following:

1. Unequal test-group sizes may have impacted statistical analysis. This issue may have caused some inconsistencies in statistical testing of mean values between groups.
2. Snowballing, a technique where participants send the link to anyone they deem qualified, was encouraged for participants (as in Baltar & Brunet, 2012). It is difficult to measure the effectiveness of the snowball technique in this study. What makes this technique advantageous is that those surveyed felt empowered to include their colleagues, making determining the test population and response rate difficult.
3. Survey fatigue in the test groups lowered participation. The pilot study group was surveyed several times during the year. The timing for the pilot study was at the end of the year, which corresponded with the holidays. Survey fatigue

was also an issue mentioned by several respondents from commercial space companies. The mitigation step to limit survey fatigue was keeping the anticipated survey-completion time between 12 and 16 minutes.

4. Kurtosis values were higher, showing higher skewness. Skewness was anticipated, given that the Likert-type scale questions showed strong reactions.

Scope of Research

The study did not address all possible issues surrounding the implementation of an SMS or determine SMST attribute issues related to commercial space operations. The study also did not cover all the aspects related to HRT-specific questions in airlines companies. The pilot-study survey was available for 4 weeks from December 19th through January 6th. The main survey testing of the commercial space groups and the airline group was for 4 weeks from February 7th through March 7th.

The study was limited to participants from various aspects of commercial space operations. These included those working in the production of rockets or satellites and launch and recovery operations. Participants from the airlines possess a working knowledge of SMS by training and experience from their respective companies. Participants included pilots from flight operations and flight attendants from inflight operations. The scope for both groups included various levels, from new employees to senior managers.

Expected Findings

Survey results were anticipated to show that some SMS attributes produce comparably high mean values for commercial space companies when compared to the airline results. These values, if similar, signified a level of acceptance of SMS concepts. Additionally, the expectation was that those who worked in an airline SMS environment would comprehend some HRT attributes. An acknowledgment seen through the mean values would have signified a level of acceptance of underlying HRT concepts, showing similarities in HRT mean values between the two groups.

Summary

The commercial space industry is expanding to accommodate the demand to take crewmembers, materials, and satellites into space. The industry will continue to grow as space tourism becomes a feasible option for more people. As the commercial space industry expands, the FAA/AST will determine a standard safety-management protocol for all companies. Much like the commercial airline industry, managing a standard safety protocol may prove beneficial to the FAA/AST as well as to individual companies. This research study attempted to determine whether SMS attributes exists in commercial space companies. This determination may help bring an SMS to the commercial space industry more efficiently.

The attributes of HRT are advantageous in various aspects of the medical industry. HRT is not, in itself, a safety protocol. Instead, HRT is a list of attributes shared by members of a company. Understanding whether HRT exists in airlines may help amplify current safety protocols and increase safety awareness. HRT attributes may be perceived as independent of each other. Determining recognition of HRT attributes in the airline industry may offer augmentations to existing safety protocols. Identifying whether one or more HRT attitudes exist naturally may allow an airline to expand, include HRT training, and increase awareness of the elements.

CHAPTER 2

LITERATURE REVIEW

The existing literature describes topics such as commercial space, safety culture, SMST, and HRT. To date, few published articles exist detailing HRT in an airline SMS environment or SMST in a non-SMS environment in commercial space. This chapter provides a review of the literature on the growth of the commercial space industry, safety culture, SMS/SMST, and HRT.

Safety Culture

In general, the foundation of an organization's levels of safety relates to whether all levels of the organization have accepted the safety culture. A group's culture is the overall genetic building blocks that any successful organization needs to foster and is arguably the most critical organizational element needed for a successful company (Reason, 1998). An organization's ability to gauge how well the safety culture is functioning depends entirely on how the group defines it (Glendon & Stanton, 2000). Five contributing factors define safety culture: informed, flexible, reporting, learning, and just (see Figure 4; Reason, 1997).

A common cause organization like the U.S. Air Force has a complex safety culture (J. M. Smith, 1998). "If the culture is shared and endorsed across the various subgroups that comprise the organization, then a sense of mission exists, and the organization is relatively cohesive, both internally and in its approach to the outside world" (J. M. Smith, 1998, p. 41). This may hold true for any aerospace organization as well. Defining a safety culture is similar to defining a healthy culture, as both include words that are quite broad with meanings that are difficult to encapsulate comprehensively (Reason, 1997, 1998). Moreover, if senior management perceives a safety culture negatively, those actions may adversely influence others in the organization, resulting in a decline in the overall safety culture (Antonsen, 2009; Reason, 1998.

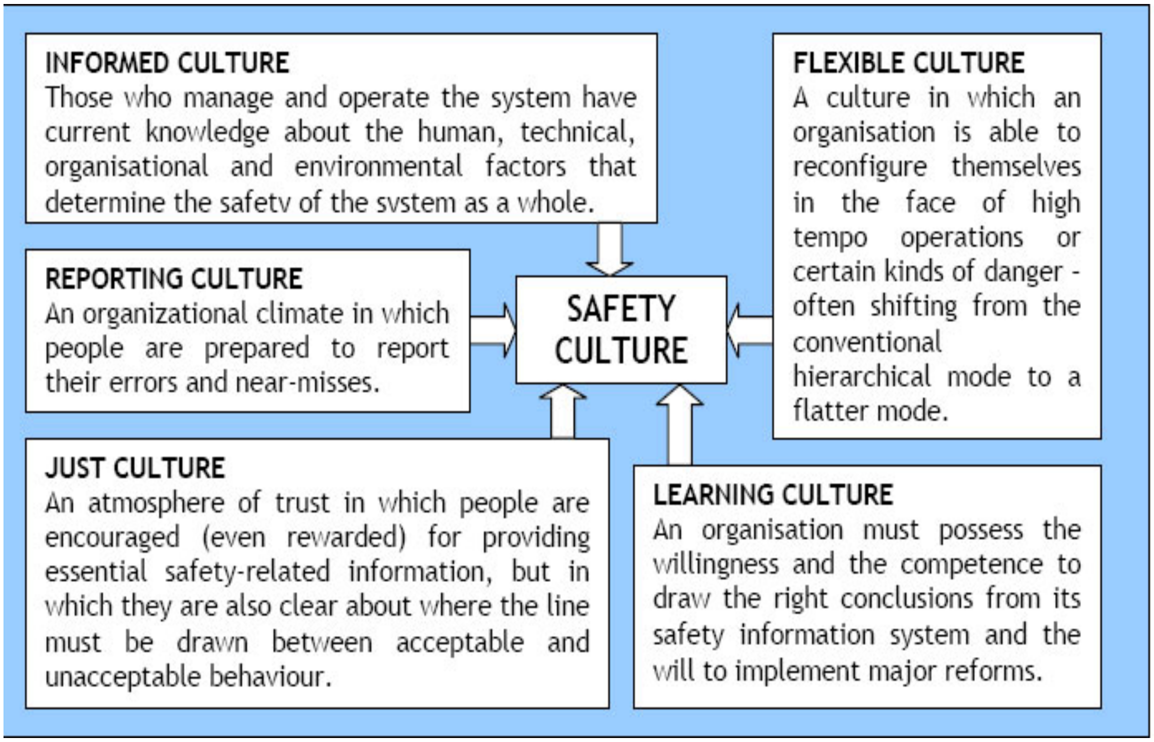


Figure 4. The components of safety culture.
Note. Adapted from *Managing the Risks of Organizational Accidents,* by J. Reason, Burlington, VT, US: Ashgate. Reprinted by permission from the Global Aviation Information Network.

Management must be careful when using culture to rationalize mistakes that do not make sense for the company (Myers, Nyce, & Dekker, 2014). This caution is true for a reporting culture as well. Some members of an organization may negatively influence the group's reporting culture (Vaughan, 1997). Organization members may not always follow the prescribed safety procedures and, if reported, may cause needless changes to current safety procedures (Dekker, 2003). Accordingly, a safety culture includes how people in the organization think and act.

Any organization's patterned way of thinking reflects its essence or the belief of the groups around its core (J. M. Smith, 1998). Without a robust organizational culture, it is unlikely a company can function properly (Schein, 2010). Traditionally, an organization's management dictates culture. The goal is to have all employees of the organization adopt a positive safety culture encompassing all five elements. (Nævestad, 2009). At its core, culture appears to require a formal, systematic safety program that may be similar for aviation, space, medicine, and other high-risk organizations (Guldenmund, 2010). The development of a safety culture grows over time and directly relates to the environment of the company (Guldenmund, 2010).

Safety Management System Theory

The theory of safety management and SMS stem from systems engineering and quality management from Hale, Heming, Carthey, and Kirwan in 1997. Moorkamp et al. (2014) wrote the first journal article to use the term SMST to define the research Hale et al. (1997) had completed in describing the functionality of an SMS. An SMS is a comprehensive, formal, process-based safety structure that includes official descriptions of duties, practices, actions, and processes for risk management first instituted in the early 2000s (Álvarez-Santos, Miguel-Hávila, Herrera, & Nieto, 2018; Liou, Yen, & Tzeng, 2008; Stolzer et al., 2018). An SMS may also be an agreement with a governing agency that may require adjustments to the process to remain in compliance with the corporation's proactive commitment to safety (Hale, 2003; Liou et al., 2008). The origins of SMS come from a well-defined, formal management structure described by division, duties, practices, actions, and processes for risk management (Álvarez-Santos et al., 2018).

SMST includes several safety practices ranging from safety management to safety culture, normal-accident theory (NAT), and HRT (Moorkamp et al., 2014). The orientation of safety-management theory is toward an organization's administration and safety control processes, aiming to minimize operational uncertainty (Hale et al., 1997). SMST is more specific and includes all process areas of an organization (Hale et al., 1997). SMST incorporates the elements needed by a management team to curtail safety ambiguity in operations. Regardless of the theory, Dekker (2005) challenged the idea that addressing and reducing all environmental ambiguity to attain safety is considered to be the customary everyday work of everyone in the organization. However, safety management may not be the answer for all companies and cannot take the place of sound engineering processes. Total reliance on an SMS to replace a basic understanding of how human factors interact with the operations would not increase safety (Hale, 2003). Adopting a safety program without understanding or planning how it will integrate into operations can create safety-culture issues in the organization (Hale, 2003; Hale et al., 1997). Without full support of the entire organization, from senior management to line worker, an SMS will not succeed.

The SMS as a management tool has become a standard for some organizations of risk, including airlines, air traffic control, and the medical industry (ICAO, 2013; Moorkamp et al., 2014). European government regulatory agencies moved to install a structured, standard safety protocol across various companies in certain industries. This philosophical change stemmed partly from the desire of governments to cease the detailed regulatory tasks of managing the individual safety programs of different companies (Hale, 2003). Instead, by focusing on a universal standard, government safety monitoring became streamlined across an industry. This desire led to the development of an SMS framework in many European industries (Hale et al., 1997). The aspiration for safety consistency led to the development of the standards used for early SMS programs (Hale et al., 1997). An SMS cannot be a static program for an organization. Like all safety programs, it requires adjustments to reflect changes to internal and external influences with ongoing modifications to the operating environment.

SMSs have become widely recognized as providing a systematic approach to managing safety that includes the necessary critical parts of organizational structures, accountabilities, policies, and procedures (ICAO, 2013). This approach seems to be in line with programs listed in the FAA/AST's SMS manual for future initiatives for commercial space companies (FAA, 2015a). To date, no published implementation timeline exists for an SMS in the commercial space industry.

Companies adopting the formal SMS structure had higher safety performances than those that did not (Bottani, Monica, & Vignali, 2009). However, adopting an SMS was clearly insufficient without the leadership to advance the program (Pariès et al., 2018). Programs require constant monitoring of the processes to maintain safety (Remawi, Bates, & Dix, 2011). Safety directions, as well as promoting a positive safety culture (informed culture, flexible culture, reporting culture, learning culture, and just culture), must come from top company leadership (Fernández-Muñiz et al., 2007). Nevertheless, not all companies are candidates for a SMS. An organization that does not share key safety policies or distribute safety information in the company may not be successful in the adoption of an SMS (Álvarez-Santos et al., 2018). For example, in discussing the rapid assault forces of Dutch military expeditionary forces, organizations requiring rapid adjustments may not have benefitted from an SMS (Moorkamp et al., 2014). An SMS program did not seem nimble enough to make quick operational adjustments required by an organization and required constant major adjustments.

The design of an SMS allows for continuous improvements to safety by actively identifying hazards, collecting and analyzing data, and assessing risks (Stolzer et al., 2018). Different from other programs, an SMS incorporates the whole organization with the vision and direction coming from top management (Chen & Chen, 2012, 2014; FAA, 2015b; Hale et al., 1997). However, a classic top-down approach might not possess the flexibility needed to work in a dynamic situation where operational flexibility may be required (Rasmussen, 1997). SMS success hinges on the level to which each member feels integrated into the program being led by senior management. Although an SMS is adjustable for any size company, not all companies will have a successful SMS program.

For an SMS to be successful in an organization, the program must be employee-centric (Chen & Chen, 2012). In contrast, if the foundations of a positive safety culture are not met and internal communications begin to falter, the organization may begin to drift away from standard operating procedures. The effectiveness of the safety culture dictates whether a company can successfully implement an SMS (Chen & Chen, 2012; Gordon, Kirwan, & Perrin, 2007). Robust organization-wide safety design with risk and hazard identification and management processes, including safety assurance, must be founded on a complete understanding of all processes, employee functions, and all other internal and external forces (Arendt & Adamski, 2016). In the absence of a social-technical development approach, organizations that do not emphasize employee social interactions or value identifying risk-prevention opportunities to improve the operation the program will not prosper (Álvarez-Santos et al., 2018). How an employee views the organization's SMS program affects their overall operations decision-making (Chen & Chen, 2014). The SMS design emphasizes the need for a unified team to proactively manage the safety of the group. Successful SMS practices directly relate to the safety self-talk of each member, impacted by the actions of management (Chen & Chen, 2014). Often, SMS studies are only direction-oriented and do not strengthen the beliefs, values, and commitments that drive adoption by the group (Álvarez-Santos et al., 2018). A company or government agency cannot merely force a safety protocol on its members. An emotional work–employee connection increases the chances for success and strengthens the culture of the organization. How management expresses their views of safety has a direct impact on an employee's view of the importance of safety (Fernández-Muñiz et al., 2007). Without management's complete understanding and acceptance of SMS, the program will not prevail.

The FAA mandated the use of an SMS for all airlines, replacing what had been their former safety structures and procedures. A company with an SMS may expect to see reductions in the duplication of safety tasks, resulting in lower costs with a reduction in overall risk. Eliminating any repetitious duties could increase profits and streamline responsibilities and relationships. However, simply instituting an SMS will not always deliver an increase in safety levels. A critical element for the FAA was to have SMS compliance from all commercial airlines accompanying the advantage of cost savings or a lower financial burden for operators (Lercel, Steckel, Mondello, Carr, & Patankar, 2011). The requirement for management was to prepare the organization for the program and make any necessary adjustments to the safety culture (Hale, 2003). At the micro and macrolevels, cost savings only appear if the organization's safety culture feels fully supported by senior management.

SMS has seen an increased in acceptance from several industries. The U.S. aviation industry began the adoption of an SMS in 2010 with mandatory implementation in 2018 (FAA, 2015a). This implementation came years after European airlines and other international companies had adopted the program. Some industries outside the airlines were quicker to adopt the safety program. The question remains whether the voluntary implementation of an SMS is advantageous for all organizations. Some in the medical industry appreciated the advantages of the risk-mitigation elements of SMS and began to implement the safety-management protocol (Wilf-Miron et al., 2003). The medical field also recognized the benefits of HRT attributes and adopted HRT to augment safety management as well (Sutcliffe, 2011).

> Several safety strategies can fit with an SMS framework, including numerous models, theories, or other safety programs. Among them, High Reliability Organizations (HRO), and the Resilience Engineering (RE) movements have received increasing attention in recent years. Particularly after the Fukushima disaster in March 2011, because they address the management of the unexpected. (Pariès et al., 2018, p. 1)

Opportunities may exist to augment safety procedures and understanding beyond the traditional framework of an SMS through the addition of other safety features.

Figure 5 depicts a framework for a possible commercial space proactive SMS.

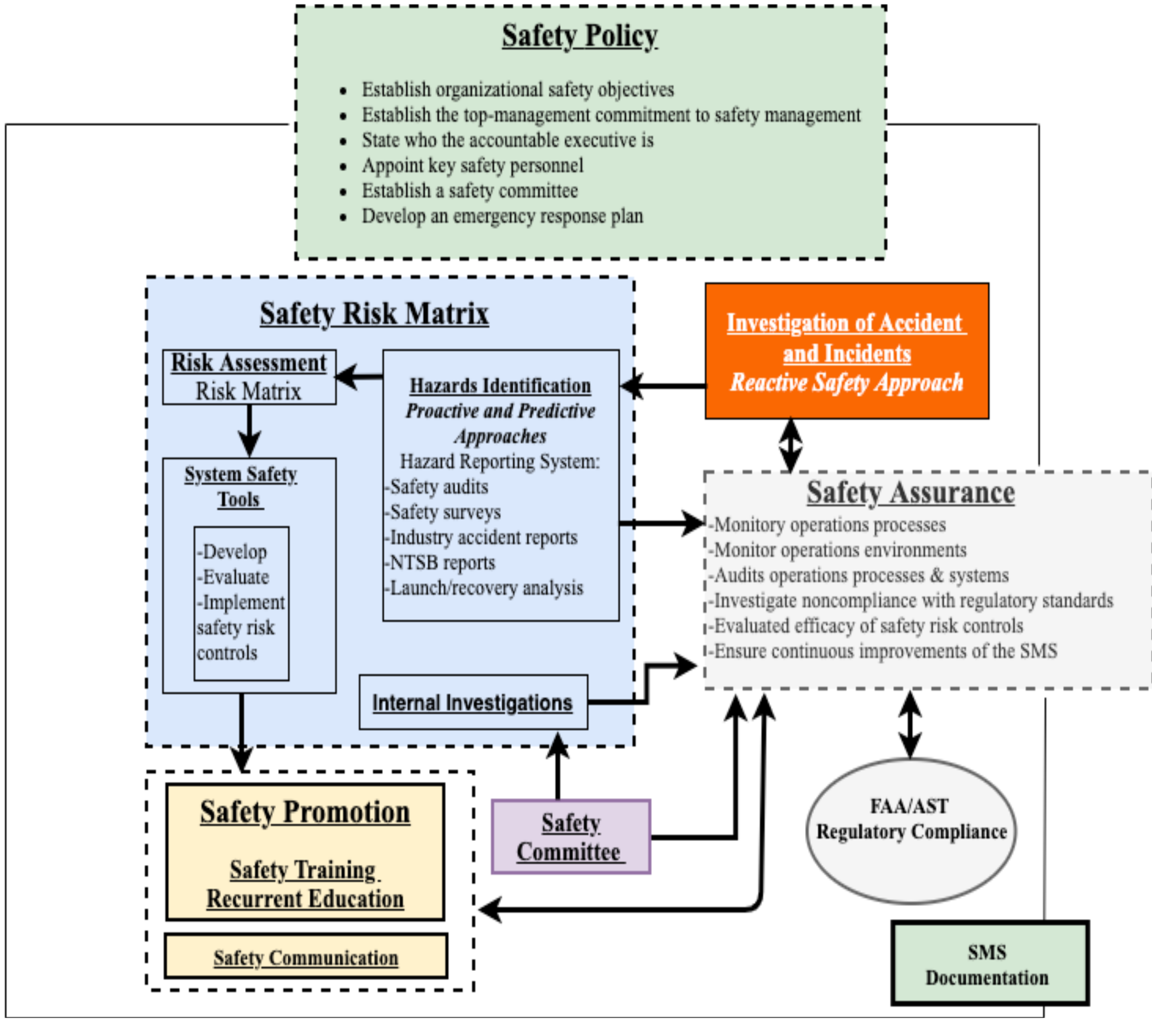


Figure 5. A Safety-management system model for commercial space organizations. *Note.* Adapted from A Safety Management Model for FAR 141 Approved Flight Schools, by F. A. Mendonca & T. Q. Carney, 2017, *Journal of Aviation Technology and Engineering, 6*(2), 3. https://doi.org/10.7771/2159-6670.1144

Safety management system components. Chen and Chen (2012) stated that SMS, as a proactive safety model, was different from other safety structures in aviation, medicine, or nuclear power. The FAA SMS manual (2015a) indicated that the elements of an SMS include safety policy, SRM, safety, and safety promotion (see Appendix A). For an organization to have an SMS, all four components must be included in the safety system (Chen & Chen, 2012; Stolzer et al., 2018). Figure 6 shows the FAA's image of how the four elements of SMS interact.

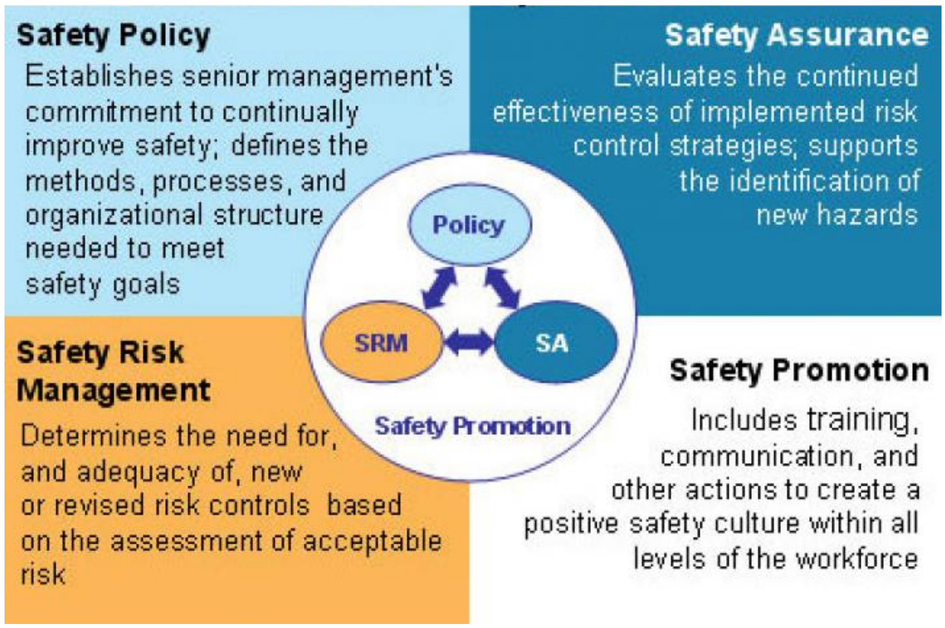


Figure 6. Safety management system.
Note. From *Safety Management System for Domestic, Flag, and Supplemental Operations Certificate Holders; Final Rule,* by Federal Aviation Administration, 2015a, Washington, DC, US: U.S. Government Printing Office.

Safety policy. According to the FAA's SMS manual (2015a), safety policy is the foundational document of the SMS that expresses the commitment that management makes to improve safety incrementally. The policy identifies the key senior manager ultimately responsible for upholding the safety of the organization (ICAO, 2013). The manual also describes any procedures, practices, and organizational configurations needed to meet the safety goal (FAA, 2015a, 2015b; Stolzer, Halford, & Goglia, 2008, Stolzer et al., 2018). It is incumbent on management to set specific, well-defined safety objectives for the organization that will achieve a high level of safety (Chen & Chen, 2012, 2014; Stolzer et al., 2018). The SMS document includes any necessary policies, safety processes, and operations methods necessary for the organization to successfully implement an SMS and includes information on emergency preparedness under the policy section, providing the organization's procedures in the event of an emergency event (FAA, 2015c; ICAO, 2013). The goal of the emergency-preparedness plan is to mitigate negative effects on the company caused by an unplanned event.

Safety risk management. The SRM process is a formal procedure used to determine any new requirements or adjustments to the existing risk-control mitigation methods. The SRM process is iterative and based on the appraisals of acceptable risk to the organization (FAA, 2015b). Companies develop an SRM method over time that must be adjusted as needed for ongoing additional threats. An SRM process is a proactive tool used to determine hazards through the analysis of collected organizational-safety information (Velazquez & Bier, 2015). A well-structured safety-risk matrix allows for adjustments to operations through active hazard and risk identification (Stolzer & Goglia, 2015).

Safety assurance. Safety assurance is a process organizations use to evaluate the efficacy of the SMS. Companies maintain safety assurance by measuring the current safety methods against the expected safety goals set for the organization (Velazquez & Bier, 2015; Stolzer & Goglia, 2015). Consistent analysis of safety data helps produce the information needed to maintain strong risk mitigation controls. Consistent analysis is the means of evaluating the organization's ongoing operational situation (Dekker & Woods, 2009).

Safety promotion. The fourth component consists of safety promotion. Safety promotion comprises a company's training, learning, and safety communications (FAA, 2015b; ICAO, 2013). This section contains the recurrent training requirements that help reinforce the idea of safety responsibilities, the safety policy, and reporting procedures (FAA ATO, 2017). The initial and recurrent safety training and appropriate communications are the basis for fostering a robust culture of safety (Stolzer & Goglia, 2015).

Scalability. By design, companies of any size can implement an SMS. The complexity of each organization's SMS program should be adjustable to the size of the organization (FAA, 2015b). A strong safety culture should be prevalent in the organization where members are integral to the success of the operations. An SMS is scalable to individual organizations and defined by four traditional elements. Safety policy, safety risk assessment, safety assurance, and safety promotion must all be present to be considered an actual SMS. If one SMS element is missing, it ceases to be an SMS and becomes just a safety program (G. Ullrich, personal communication, September 18, 2019). Although each SMS may be customized, each will have elements that will work in conjunction (Chen & Chen, 2012).

Implementation. Organizations implement SMS safety protocols in four stages (ICAO, 2013; see Figure 7). In Phase I, organization lay the foundation of what the safety policy will entail and identify the accountable executive (ICAO, 2013). Also included in this phase is a gap analysis between available organizational resources and the requirements from a national or international government agency. Phase II entails a reactive safety-management process that includes the implementation schedule of the program, training, documentation, and development of a means of safety communication (ICAO, 2013). Phase III, the proactive and predictive safety-management process, refers to a refinement of the process in the organization, including changes to training based on safety data (ICAO, 2013). This phase also allows for any additional safety programs to be implemented and adjustments to current safety policies based on historical and forecasted safety data. Phase IV is the operational safety-assurance phase that encapsulates use for performance indicators and performance targets and allows for continual improvement of SMS processes (ICAO, 2013).

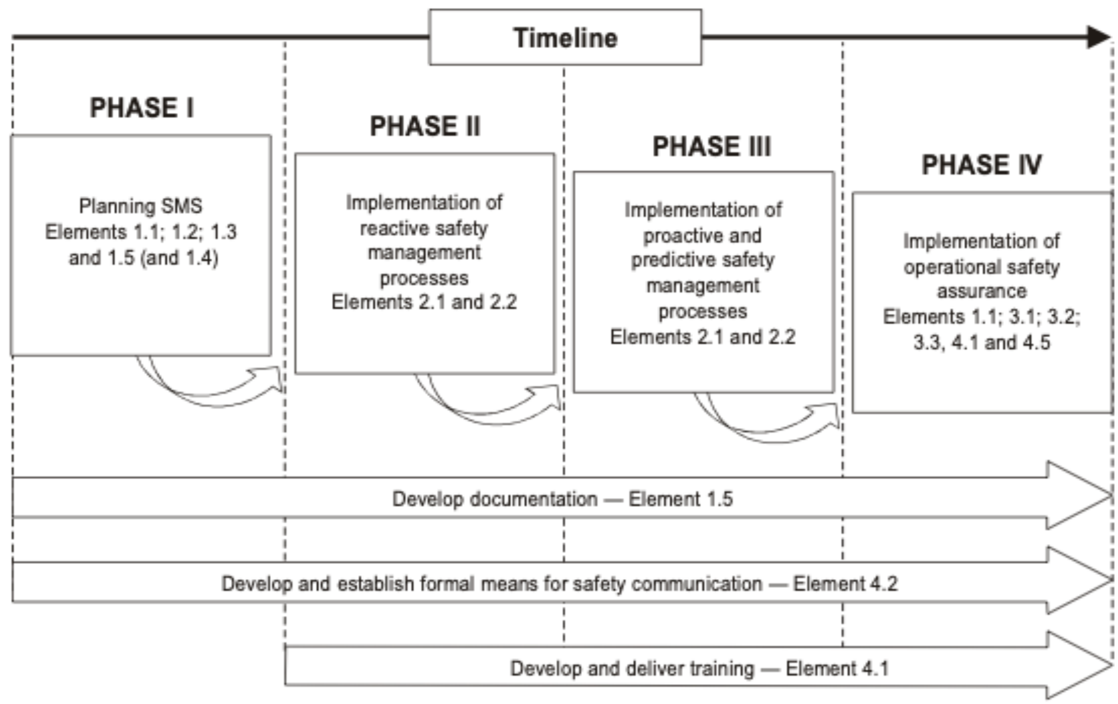


Figure 7. Safety management system implementation phases.
Note. From *Safety Management Manual (SMM)* (3rd ed.), by International Civil Aviation Organization, 2013, Montreal, Canada.

High-reliability theory. High reliability emerged from a group of researchers at the University of California, Berkeley, observing a Navy carrier operation in the 1980s, searching for what factors in safety culture offered virtually risk-free operations (Weick & Sutcliffe, 2015). HRT defines the level of focus required from all levels of the organization to maintain a consistently high safety level in the operation with all the intrinsic hazards (Dekker & Woods, 2009). An HRO is an organization that exhibits the core characteristics of preoccupation with failure, reluctance to simplify, sensitivity to operations, commitment to resilience, and deference to expertise through mindfulness while staying error-free in the management of dangerous systems (Boin & Schulman, 2008; Weick, 1987). HROs also can quickly return to a state of normalcy after hazard events.

HRT consists of attributes seen in high-risk complex groups with dangerous functions that operate virtually error-free (Enya, Pillay, & Dempsey, 2018; Roberts & Bea, 2001). However, HRT and NAT are two concepts that describe accident rates surrounding hazards found in a high-risk company (Weick, Sutcliffe, & Obstfeld, 1999). HRT researchers uncovered specific organizations taking extraordinary measures to remain error-free in a high-risk industry (La Porte & Consolini, 1991; Weick et al., 1999). HRT evolved from the concept that success relates to maintaining a closed organizational structure but evolved to accept external influences (i.e., FAA/AST regulations in the case of aerospace companies; Weick et al., 1999).

Mindful organizing. Organizational leadership has a large positive or negative impact on the acceptance of SMST or HRT by members of HRT groups. Safety culture cannot merely be forced from those in power (Gordon et al., 2007). To achieve an HRO or an SMS, leadership dictates how group culture will evolve (Schubert, Arbinger, & Sola Morena, 2016). For any organization, culture is the institution's set of beliefs and attitudes that frame the group and develop robust positive safety values (Remawi et al., 2011).

The idea of central collective mindfulness is a requirement for a high-risk organization to remain accident-free (Weick et al., 1999; Weick & Roberts 1993).

Mindfulness is how organizational members intertwine the five HRT attributes and remain mindful of other issues that may need attention through the actions they take. Mindfulness is a learned trait that requires questioning the status quo and focusing on accident prevention. It is essential to recognize adverse trending events early enough to make a straightforward adjustment before these events result in catastrophic issues. Having effective people in the appropriate positions is key to allowing for early safety decision-making, fostering a feeling of employee ownership in the program (Dekker & Woods, 2009; Vogus & Sutcliffe, 2007; Weick & Sutcliffe, 2001, 2006, 2015). Perceived ownership is a crucial element for successful organizational mindfulness (Weick & Sutcliff, 2015).

Collective mindfulness consists of five interrelated behavior processes: preoccupation with failure, reluctance to simplify the operations, sensitivity to the operations, commitment to resilience, and deference to expertise (Vogus & Sutcliffe, 2007). The five elements tie together through a collective mindfulness that all members practice (Haavik, 2014; Weick & Sutcliffe, 2001, 2006, 2015). The safety culture of employees is augmented in HROs through collective mindfulness (Weick &Sutcliffe, 2006).

When considering HRT attributes, qualities of culture provide insights into the context of care that directly influences reliability (Pronovost et al., 2006). A proven method of improving safety and increasing the quality of an organizational output is HRT, consisting of organizational design principles and improved management approaches that lower error rates and improve overall safety (Riley, Davis, Miller, & McCullough, 2010). HRT includes a complete group commitment to safety, multiple methods for task completion, well-designed safety measures, and a whole-group organizational learning culture (Pronovost et al., 2006; Riley et al., 2010). However, several elements shape an organization's culture including policies, procedures, observed practices, and personalities of leadership. Rank and file members also have a role in shaping the safety culture. Organizations need to include real-world training environments to foster the skills needed by newer members of the group to more quickly adopt HRO facility (Rochlin, La Porte, & Roberts, 1987). Figure 8 depicts mindfulness as a conduit for HRT attributes.

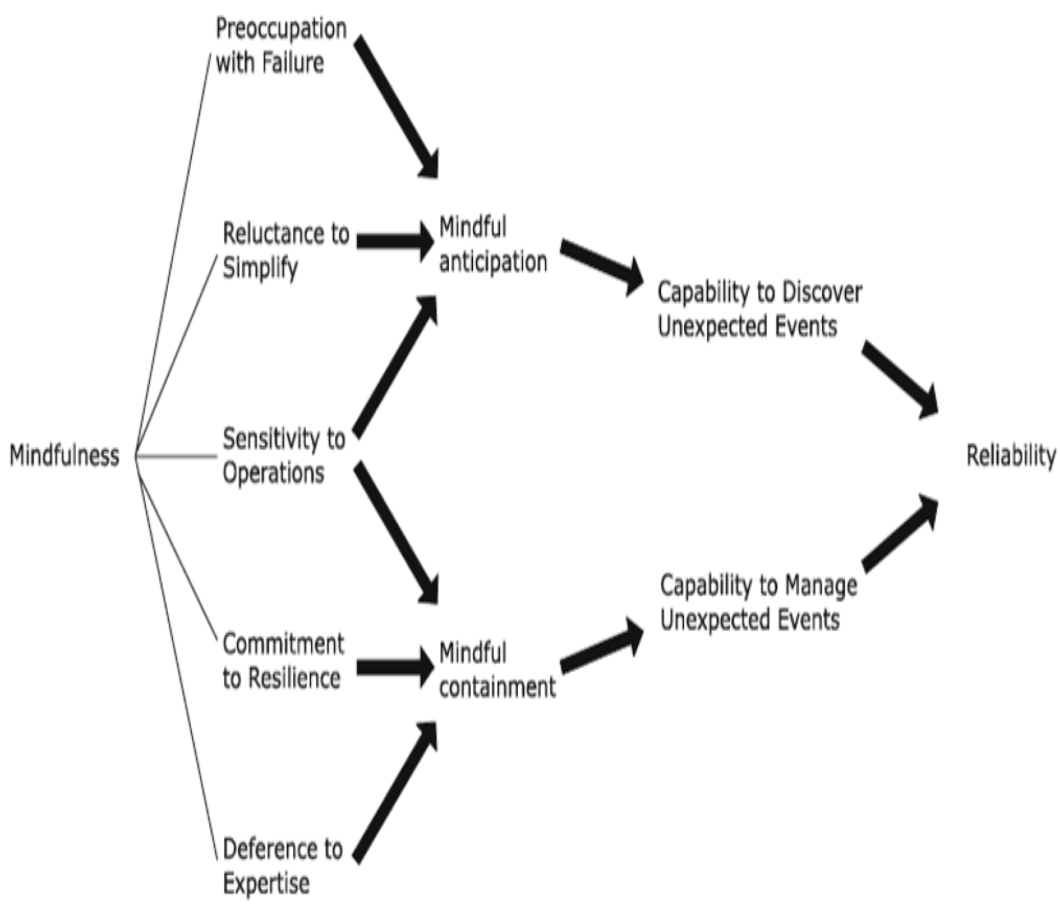


Figure 8. High reliability theory flows from mindfulness.
Note. From Van de Walle, B., & Turoff, M. (2008). Decision support for emergency situations. *Information Systems and E-Business Management*, *6*(3), 295–316. doi:10.1007/s10257-008-0087-z. (p. 300).

High Reliability Theory Components

Preoccupation with failure. Preoccupation with failure includes a detailed focus on all activities in the organization (Haavik, 2014; La Porte, 1996). Preoccupation includes increased alertness, maintaining an open mind to alternative ways of completing the job, and anticipating issues (Hales & Chakravorty, 2016). HRT avers members communicate openly, regardless of rank, and without fear of reprisal (Lekka, 2011). An event considered a "close call" becomes an accident in the eyes of the company. These events may result in procedural changes to alter safety methods (Lekka, 2011). Management encourages the reporting of unfavorable events, and those who bring the information forward are rewarded for doing so, fostering an open culture. Management celebrates reporting an issue that turns out to be inconsequential.

Sensitivity to the operation. The sensitivity to operations is a common element among members of the organization who exhibit HRT attributes. Members of the group pay particular attention to every detail of the operation and should be open and available for input anywhere when needed (Hales & Chakravorty, 2016). Upper managers cross-trained for various duties are available to act as frontline employees when needed (Vogus & Rerup, 2017). Members expect job feedback and are encouraged to expand their skill sets beyond their job duties. This trait allows individuals to expand their skills to create mission redundancies (Saunders, 2015). This cross-training allows associates to assist with other areas as necessary, thereby expanding safety effectiveness during a time of need.

Reluctance to simplify. The reluctance to simplify relates to an organization characteristic that does not accept simplifications for procedures used in daily operations.

Employees are encouraged to gain operational diversity that questions the current status of the operation at all times (Hales & Chakravorty, 2016). The goal is to have a complete representation of how operations are functioning at all times. Organizations that demonstrate HRT attributes do not become complacent during smooth operations, but instead maintain constant vigilance (Dekker & Woods, 2009). Continual data-driven probing of the process for errors is essential, retaining a skeptical perspective during smooth-running operations. If employees feel that an operational issue exists, they are encouraged to express their concerns to management (Pariès et al., 2018). This quality develops a high level of internal trust (Sutcliffe, 2011).

Commitment to resilience. The commitment to resilience is the ability to detect, correct, and return to a "dynamically stable" operational state quickly after a safety issue (Sutcliffe, 2011, p. 136). Organizational learning and bottom-up informational flows are essential and result in overall intellectual growth. (Marais, Dulac, & Leveson, 2004). Management encourages and expects maintenance of a just culture through innovative solutions to issues (Riley et al., 2010). HRT attributes, encouraged by organizational leaders, offer individuals opportunities to use their experience, imagination, and other outside safety examples or information to solve any problems (Marais et al., 2004). Informal discussion groups meet outside of formal organization meetings to help share knowledge among members (Vogus & Rerup, 2017). These informal discussions help retain operational knowledge that may not be covered in formal meetings, guaranteeing corporate knowledge is retained.

Deference to expertise. The final characteristic of HRT is deference to expertise. Regardless of their rank in the company, a subject-matter expert (SME) nearest a pending catastrophe is expected to take charge of the situation and make any necessary operational decisions (Saunders, 2015). All members are committed to completing their tasks but when needed, will defer to someone who may have more expertise (Riley et al., 2010). HRO group members expect someone with more proficiency to take the lead during high threats when needed (Weick & Sutcliffe, 2001, 2006, 2015).

Not all organizations can be successful HROs. Casler (2014) averred it would be challenging to implement an HRO in an organization as large as NASA, given the complexity of the organization and may be cost-prohibitive as well. Casler speculated that it might be difficult because of the required layers of infrastructure needed to maintain the overall operational attention required to be considered an HRO. However, departments or individual divisions in a larger organization may still exhibit HRT traits (Weick & Sutcliffe, 2001, 2006, 2015). For an HRO to be successful in a large networked organization, collaborative links and dynamic correction abilities would need to part of the group's overall operating structural makeup (Hall, 2016).

A second concept that addressed organizing around high-hazard technologies in organizations is NAT. NAT states accidents will happen as a function of time, regardless of any countermeasures in place (Perrow, 2011). An HRO structure could oversimplify issues faced by an organization (Marais et al., 2004). Given the complex nature that many risky organizations function in today, the HRT idea that an organization will remain rational, stable, and a closed system may not be achievable (Shrivastava, Sonpar, & Pazzaglia, 2009).

In turn, building safety-critical systems and following some HRO recommendations could have negative results. Both HRT and NAT may limit the safety progress necessary to achieve a more effective safety system by narrowly defining the problem and stemming potential solutions. A more effective method to eliminate hazards may be to reduce unnecessary complexity and decoupling operations (Marais et al., 2004), instead, increasing overall safety by eliminating opportunities for human error. Being an organization that is both reliable and safe may be in conflict (Marais et al., 2004). From an operational standpoint, a high level of interactive complexity will need a decentralized structure during specific times. When an HRO paradigm was applied to create safety under complex, risky conditions, a more optimistic group mindset may emerge than that seen in Perrow's (2011) NAT writings (Andriulo, Arleo, de Carlo, Gnoni, & Tucci, 2015).

Furthermore, organizations that are HRO are not error-free, but errors do not stop the HRO from moving forward (Andriulo et al., 2015). HRT researchers offered explanations as to why certain companies with tight couplings and complex operations have few accidents (Haavik, 2014). This idea is in direct opposition to NAT, which contends that HRT cannot prevent accidents over time (La Porte & Rochlin, 1994).

Summary

This chapter includes a detailed examination of the existing literature surrounding culture, SMS, SMST, and HRT. Although this literature review included a discussion of a majority of articles available, it did not include all. The literature review focused on the areas incorporated in the research study.

How the leadership of an organization structures its safety culture and how employees view the culture are critical to how well it operates. Safety culture is the way an organization functions, especially in times of duress. The literature revealed that the actions of management could have a positive or negative effect on the overall culture. The goal of management is to create a positive safety culture in which all members feel part of the safety structure and are empowered to have a voice when safety issues arise.

SMST is the foundation of how an SMS functions. The four main elements of policy, risk management, assurance, and promotion, are required for the system for function optionally. All four components must be in place and functioning to be considered an SMS. Early researchers indicated a high level of effectiveness and acceptance in airlines and in the medical field. However, instituting an SMS does not guarantee a safety program will result. The whole organization must be fully vested in the success of the program, including in meeting any necessary financial requirements. No research exists that attempted to predict the successful implementation of an SMS program in an organization.

HRT attributes, although not a safety structure, may be found to exist among members working in high-risk companies that have limited numbers of accidents. Early research indicated that to be considered an HRO, all five HRT attributes must be present in the organization. However, researchers described studies identifying the existence of some HRT elements in an organization not traditionally considered an HRO. Detecting HRT elements may be beneficial to the organization as an enhancement to existing safety protocols.

CHAPTER 3

METHODOLOGY

This study addresses two main questions: Do SMS attributes exist among the members of commercial space organizations who operate without an SMS? Do HRT attributes exist in airlines with an established SMS? (Henceforward, commercial space will denote a non-SMS environment and airlines will denote an SMS environment.) The design for this study was an ESMM with grounded theory (GT) using the Delphi method. The methodology was divided into three parts: qualitative, survey-instrument design, and quantitative analysis.

The qualitative portion explored the theories of SMSs and HROs. Data accrued that included peer-reviewed articles, published surveys, and personal communications with SMEs. The qualitative process uncovered SMST and helped the researcher develop the questions needed for the SMS survey. The second step was the development of a new survey instrument designed to test the existence of SMS attributes in commercial space. The third step entailed a quantitative assessment of the survey results from the commercial space and airline groups.

The goals of this study were to create a means to identify underlying SMS attributes in commercial space organizations. Further, a study goal was to determine whether HRT attributes exist naturally in airlines. The researcher aspired to add to the current body of literature on SMST and HRT with the results of the research. The conclusions may offer commercial space companies the tools to conclude a financially economical means to implement an SMS as the formal safety protocol. Additionally, the results may also establish whether HRT attributes can be a safety-augmentation element in SMS environments.

Exploratory, Sequential, Mixed-Method with Grounded Theory, and the Delphi Method

An ESMM design was used to gather the necessary qualitative data using a GT approach. The ESMM consisted of a research process that was qualitative and quantitative. Exploratory sequential studies tend to use GT to generate a model or framework that guides instrument development for the quantitative phase (Guetterman, Babchuk, Howell Smith, & Stevens, 2019). Creswell and Creswell (2018, p. 224) stated,

> "In this design, the researcher would first collect focus group data, analyze the results, develop an instrument (or other quantitative feature such as a website for testing), and then administer it to a sample of a population. In this case, there may not be adequate instruments to measure the concepts with the sample the investigator wishes to study. In effect, the researcher employs a three-phase procedure with the first phase as exploratory, the second as instrument (or quantitative feature) development, and the third as administering and testing the instrument feature to a sample of a population."

Exploratory designs are sequential with the qualitative portions conducted first, building to a quantitative study (Guetterman, 2017; Guetterman et al., 2019). The qualitative research allowed the data to surface to formulate or uncover any applicable theories for quantitative testing.

The researcher's 20 years of experience in major airline operations including the knowledge and use of an SMS aided in SMS-attribute generation and SMST recognition.

The study required a set of crafted survey questions that examined understanding of SMS protocol attributes by those unfamiliar with an SMS. Constructivism was used to develop the necessary questions for the survey instrument. A perspective that incorporated the survey participants' work environment and the researcher's experiences helped in framing the questions (Creswell & Creswell, 2018).

A review of existing literature presented SMS and HRT characteristics or descriptive language, coded to create attribute lists. The GT process facilitated grouping similar components into common concepts identified during the iterative process. The repeated process further refined the concepts into codes or specific word combinations used to guide formulation of SMS-attribute questions.

In a mixed-methods study, theory development or existing theory advancement may come from a deductive (i.e., testing and validity) or an inductive (i.e., emerging qualitative theory or pattern) process (Creswell & Creswell, 2018). This researcher used an inductive approach for this study. SMST, discussed by Moorkamp et al. (2014), was selected as the underlying theory to generate SMS questions.

Several personal communications with SMEs in the fields of SMS, HRT, SMS initiatives at the FAA/AST, SMS in airlines, and SMS in academia were conducted. These communications were valuable in adding clarification to the study. Several specific discussions were instrumental in formulating the needed survey questions.

A pilot test group comprising SMS users was used for validation. Once completed, the combined survey was tested at commercial space- and airline-industry organizations. The results from the two groups were compared for statistically significant differences in mean values. Figure 9 shows the ESMM methodology, qualitative and quantitative, with the use of comparison between the two sets of results.

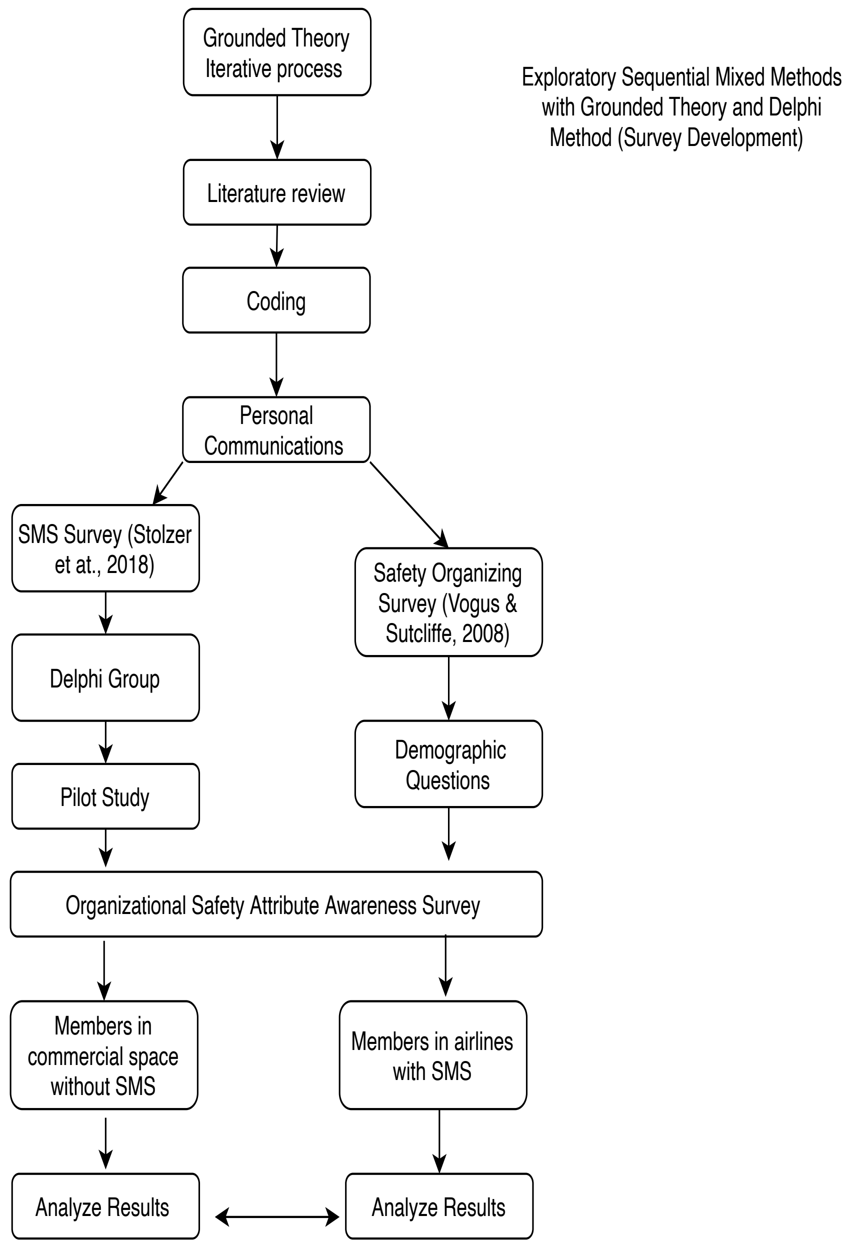


Figure 9. The exploratory, sequential, mixed-method. (Teske, 2020).

Rationale for the Method

The use of ESMM research design was appropriate, given the investigative nature of the research project, the desire to further existing theory, and work to develop a survey instrument. The steps included the three-part design showed in Figure 10.

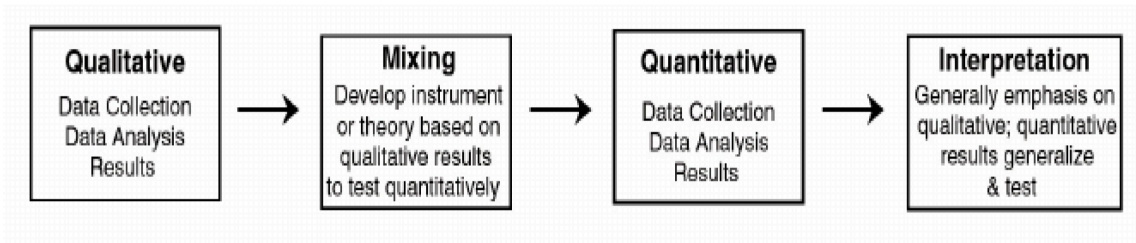


Figure 10. Three-step exploratory, sequential method.
Note. From Plano Clark, V. L., Huddleston-Casas, C. A., Churchill, S. L., O'Neil Green, D., & Garrett, A. L. (2008). Mixed Methods Approaches in Family Science Research. *Journal of Family Issues*, 29(11), 1543–1566. p. 1551. https://doi.org/10.1177/0192513X08318251

The orientation of the qualitative approach was the description, explanation, and study of the relationship between variables (Creswell, 2014. Neither a stand-alone qualitative nor a quantitative research methodology would have answered the research questions or adequately tested the hypotheses (Creswell, 2014; Creswell & Plano Clark, 2018; Ivankova, Creswell, & Stick, 2006). A plethora of established peer-reviewed literature was available that discussed the fundamentals of SMSs. Limited literature was available that directly examined SMST attributes for use in survey questions that addressed participants in a non-SMS environment. The sequential mixed method worked well with GT in creating lists of SMS and HRT attribute codes. A qualitative research design uncovers depiction, clarification, and the relationship between or among variables (Creswell, 2014). A quantitative data methodology was used to analyze the survey results.

GT was the appropriate research method given the flexibility in the methodology, the ability to code the literature, and the search for SMS attributes, and to further existing SMS theory (aligned with Birks & Mills, 2015; Wolfswinkel, Furtmueller, & Wilderom, 2013). The iterative process allowed SMS attributes, safety management theory, and SMST to emerge. GT was especially useful because the scope of the research aimed to determine whether commercial space participants would recognize SMS attributes (Strauss & Corbin 1997; Wolfswinkel et al., 2013).

A Delphi method was an acceptable method used to modify the needed questions. The selected SMEs worked independently from each other (Avella, 2016). This separation allowed for the totality of ideas to be considered equally until consensus was reached. The Delphi method resulted in the questions used for the SMS survey (Birks & Mills, 2015).

Limitations

The ESMM caused the study to have a few limitations. The methodology was time consuming for this research study. First, an extensive qualitative review of the pertinent available data was conducted to code the attributes for an SMS with high reliability. An existing survey instrument had not been published that tested for SMS attributes in a non-SMS environment. The qualitative review was necessary to help create the wording of the questions needed for the survey.

The use of a Delphi method offered challenges. Choosing SMEs who were willing to participate posed issues. Additionally, once selected, most members participated in particular timelines. However, some members of the group did not meet the deadlines, creating timing issues with the integration of the new information. Any issues with the Delphi group were addressed through multiple communications with the group.

Research Design: Exploratory, Sequential, Mixed-Method

Participation recruitment and data collection. On October 31, 2019, the University of North Dakota Institutional Review Board (IRB) approved the research study with the survey for distribution to human subjects (see Appendix B). Permission from the Aviation Department chair was obtained to facilitate email distribution during the survey pilot-study validation. Emails were sent to qualified pilots from the University Flight Department. Qualtrics.com was used to facilitate the pilot-study survey.

Letters of support from two private commercial space companies were received as part of the IRB approval process. These letters allowed for more effective facilitation of the distribution of emails to the organization's members. Additionally, LinkedIn and Facebook were used alone, with email, and through direct messaging to enable distribution to qualified individuals who met the specific requirements for the survey.

Participants agreed to a consent form before answering the questions. If an individual did not agree to the consent form, they were precluded from starting the survey. The individuals who commenced with the survey were made aware that they could stop at any time without any adverse actions. Once the survey was completed, the results were stored on the university's Qualtrics secure online servers under IRB security requirements. No personal data, including the internet service provider or global positioning system information, were retained at any point during the research. An electronic list of those sent the survey was maintained to prevent sending the survey twice.

ATLAS.ti v8 software, which is a qualitative computer-software package allowing researchers to manage textual, graphic, audio, and video data, was used. This software is well-known in social science research and enables researchers to group data into coded sections. This software stores data on the researcher's personal computer for review and coding and augments the use of GT for analysis.

Worldview of the researcher. The worldview of the researcher was shaped by more than 20 years of major airline safety experience in passenger airline operations. These safety experiences included safety investigation, safety protocol, and working with SMSs. This knowledge directed literature searches during the initial stages of the study, guiding which specific directions to begin the analysis. Experience levels may also introduce researcher bias to the data analysis. Every attempt was made to remain aware of the potential for bias during the study. The researcher remained mindful of the possibility of bias in the research and analysis as a means of mitigating any possible effects.

Grounded theory. A GT coding process of SMS-related journal articles and personal communications with SMEs continued during this research. The use of GT helped uncover and advance research of an existing theory. GT revealed the theoretical concept of SMS used in one peer-reviewed journal article to describe the underlying ideas surrounding an SMS. In this research study, GT was used to select peer-reviewed literature, create codes for SMS attributes, and code SMS and HRT data. The iterative process of data review was used to develop descriptions or underlying foundations of SMS (Guetterman et al., 2019; Wolfswinkel et al., 2013). Reviewing and coding the literature was also accomplished using the computer program ATLAS.ti (v 8, 2018).

Articles not containing relevant information or data were discarded. This iterative process continued until sufficient data were coded to form a comprehensive representation of the required elements. Approximately 188 journal articles, books, PowerPoint presentations, and conference papers were reviewed. The researcher created codes to group similar concepts together and to help select descriptive wording for the SMS survey questions.

One strength of a GT approach was discovery of an existing theory through data samplings (Goldkuhl & Cronholm, 2010). GT offered the opportunity to collate various types of information through numerous iterative rounds of coding. In this case, the codes fostered support for an existing theory (Glaser & Strauss 2017; Strauss & Corbin 1997). SMST, discussed by Moorkamp et al. (2014), was uncovered late in the research process. The study of commercial space participants required descriptive language for the SMS survey questions that were outside the traditional means of describing the elements. An example is, "the company has a safety management system," which was changed to "the company has a formal safety program." The use of the attributes of SMST supported the required descriptive language. Coding was used to standardize similar data for analysis through the use of keywords, gathering different perspectives under a comparable code (Goldkuhl & Cronholm, 2010; Wolfswinkel et al., 2013).

Personal communications. The researcher had several brief emails and in-person personal communications with individuals who are SMEs in SMS and HROs. Email communications with Dr. Alan Stolzer helped with the descriptive terms for SMS attributes. In-person discussion with Nick Demidovich, Program Manager, Payloads and Technologies Officer, involved in SMS development for FAA/AST, were beneficial in framing any future implementation of SMS in commercial space. These discussions assisted in guiding the research direction to augment the FAA/AST in a possible future SMS application in commercial space.

Brief, insightful email discussions with Dr. Tim Vogus and Dr. Kathleen Sutcliffe presented direction for the HRT questions used in the study. These communications contributed to the adoption of the Safety Organizing Scale (SOS) to capture HRT attributes for the research (Vogus & Sutcliffe, 2007).

Delphi method. The Delphi method is a method of collecting and grouping informed opinions from a group of SMEs (Day & Bobeva, 2005). An effective Delphi method requires selecting a panel who were considered experts on the topics or issues that were the focus of the discussion (Day & Bobeva, 2005; Skulmoski, Hartman, & Krahn, 2007). The information accrued anonymously from each participant and was kept confidential. The results of each round were scrutinized and summarized, then returned to participants for further contemplation and responses. Routine emails were sent to the group to foster the completion of the Delphi method. This cycle continued until an overall consensus in the group was reached (as described by Biondo, Nekolaichuk, Stiles, Fainsinger, & Hagen, 2008). According to Avella (2016), the use of a Delphi method applies to several types of research methodologies that include a constructivist paradigm. The Delphi method may be particularly useful with GT.

A panel of SMS experts was assembled, garnered through the literature review and personal contacts. The experts either had long academic/publishing histories with SMS, were considered experts in SMS by their practical knowledge and experiences or had researched the safety protocols for use with the FAA/AST. The members reviewed a list of questions from a validated scale published by Stolzer et al. (2018). These survey questions were the starting point for the Delphi group. The group reworded the questions to capture the elements of an SMS without including traditional words or phrases customarily associated with an SMS. In other words, the members crafted SMS theoretical questions that would evaluate the acceptance of the attributes for the participants without using the descriptive terms of SMS in the questions.

Each Delphi round took 7 days for the group to respond using a Word document and tracked changes to highlight their inputs. At the end of each round, the data were summarized, changes made to the existing questions, then returned to the Delphi group (Day & Bobeva, 2005). Agreement was determined through comments sent by each SME. The final round resulted in the completed list of SMS attribute questions. Each member was offered additional opportunities to respond with suggested changes. A consensus among the members was reached after three rounds, which is considered adequate (Skulmoski et al., 2007). Agreement on the wording emerged through additional changes or comments made by Delphi group members. Individual dialog with members confirmed agreement on the final questions.

Survey instrument construction validation through the pilot study. A pilot study was necessary, given the changes to the original Stolzer et al. (2018) SMS questions. Additional IRB approval was received on December 8, 2019, before the pilot survey was initiated. The survey began at a Midwest collegiate flying university with a seasoned SMS program in place and through targeted contact made through approved social-media outlets. The survey was restricted to those who had proven experience operating in an SMS environment. Careful steps were taken to avoid duplicate survey takers. The researcher contacted participants through email generated from the university's flight department. Additional respondents who also operated in an SMS environment were contacted through social media to augment pilot-test-group respondents.

After a 4-week testing period, the survey results were analyzed using SPSS (v. 26) statistical software. A principal component analysis was performed. Questions that did not result in a factor loading value above 0.50 were removed from the list of questions. Additional exploratory factor analysis and principal factor analysis were conducted. The results of the scree plot show that the majority of questions loaded onto a single factor, labeled SMS attributes (see Figure 11).

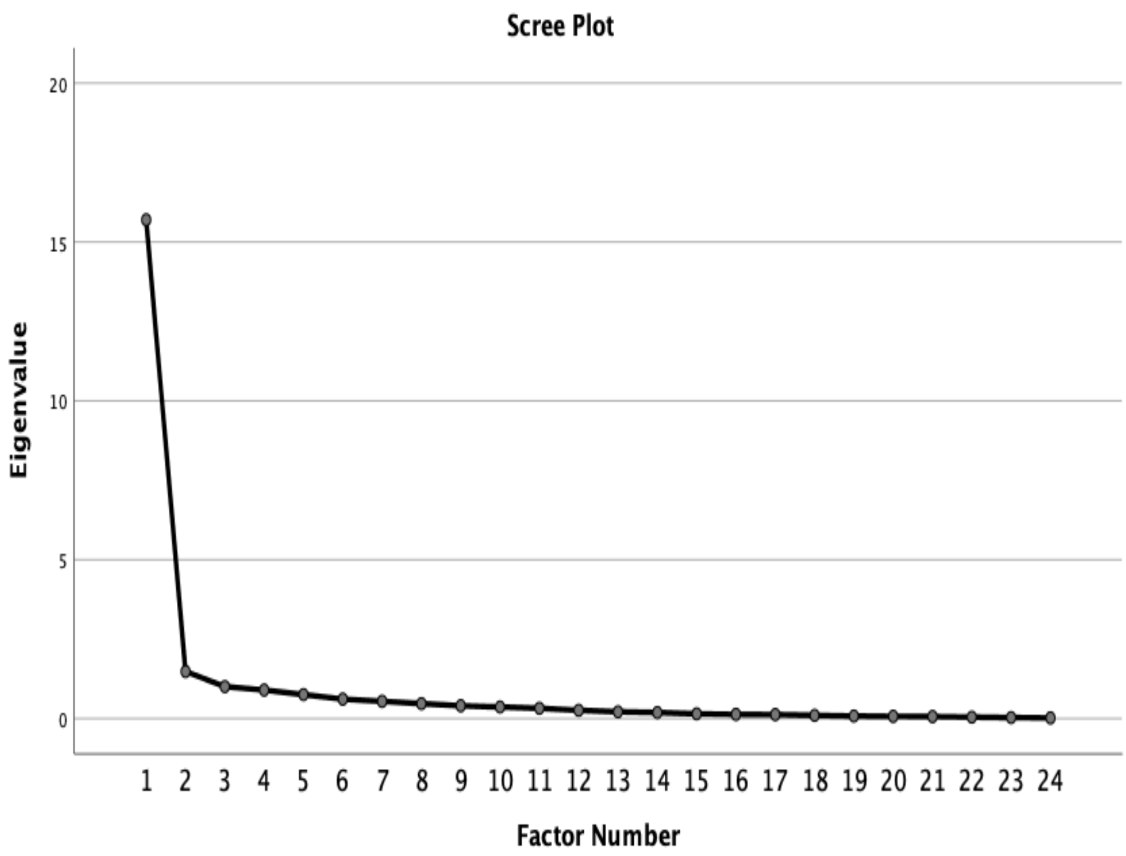


Figure 11. Scree plot from the pilot study.

The total variance explained also indicated a single factor with eigenvalue = 15.69 and a variance of 65.4%, shown in Table 2. The next factor had eigenvalues of 1.480, explaining 6.16 % of the variance. The second eigenvalue factors captured a variety of questions that did not associate with or load to a single central idea.

Table 2

Variances and Eigenvalues of Factors Extracted for Pilot Study (Edited).

Total variance explained						
	Initial eigenvalues			Extraction sums of squared loadings		
Factor	Total	Variance	Cumulative %	Total	% of Variance	Cumulative %
1	15.699	65.411	65.411	15.362	64.010	64.010
2	1.480	6.168	71.579			
3	1.005	4.189	75.768			

A parallel analysis was conducted that verified the use of one factor. The other factor loadings did not have a significant level of common elements. Therefore, the researcher elected to use a single factor for testing. Table 3 shows the results of the pilot study of the Kaiser–Meyer–Olkin = 0.833 (meritorious) test. Cronbach's α values = .963 were calculated, which showed strong internal validity. An alpha level above .70 and a Kaiser–Meyer–Olkin above 0.60 is considered to have an acceptable validity (Field, 2018; Warner, 2012). Factor loadings of 0.50 and above were retained, which resulted in 23 questions for the final SMS-attributes survey. An additional question related to SRM was included that had a factor value below 0.50. The questions were evenly distributed between the four SMS variables being surveyed. The results of the confirmatory factor analysis (CFA; principal axis factoring) are in Appendix C.

Table 1

Pilot Study Safety-Management System Theory Kaiser–Meyer–Olkin and Bartlett's Test of Sphericity

	Bartlett's test of sphericity		
Kaiser-Mayer-Olkin measure of sampling adequacy	Approx. chi-square	*df*	Sig.
.889	1051.075	276	.000

Note. Variables in the quantitative analysis.

Variables in the quantitative analysis. The resulting Organizational Safety Attribute Awareness Survey had 35 questions that consisted of 24 SMS attributes (selected from the pilot-study results), nine HRT questions adopted from Vogus and Sutcliffe (2007), and two demographic questions. In total, nine dependent variables (four for SMS and five for HRT) plus two independent variables were analyzed. Table 4 shows a listing of the questions.

Table 4

List of Factors and Variables With Applicable Questions Used in the Survey

Factors	Predictor variable	Survey questions
Safety management system theory	Policy (P)	2, 3, 5, 5.1, 6, 8
	Risk (SRM)	1, 2, 3, 4, 5
	Assurance (SA)	1, 2, 3, 6, 7, 7.1, 8, 9
	Promotion (SP)	1, 2.2, 3, 5, 6
High reliability theory	Preoccupation with Failure	PF 1- 2
	Reluctance to Simplify	RS 1- SO 1
	Sensitivity to Operation	SO 2
	Commitment to Resilience	CR 1- 2
	Defer to Expertise	DE 1- 2
Demographics	Years of Experience	D 1
	Role in Organization	D 2

Note. PF = Preoccupation with Failure, RS = Reluctance to Simplify, SO = Sensitivity to the Operations, CR = Commitment to Resilience, DE = Deference to Expertise, D = Demography.

Target population and sample. The two sample groups comprised a representative convenience sampling of individuals who, through their employer and experiences, characterized the larger population. Commercial space participants were contacted directly through an individual in their organization. Airline participants were contacted through a direct means including email, direct messenger in LinkedIn or Facebook, and posting in member-only aviation Facebook groups. The two groups were independent of each other.

Commercial space. Letters of support were received from two private commercial space companies that allowed surveying of employees. An email containing an introduction letter with URL links to the survey were sent to the contact person for further companywide distribution. All communications with the respective participants were controlled by the companies.

Additional convenience sample representative participants were contacted directly through LinkedIn and targeted emails. Individuals from the commercial space industry who received survey invitations came from Jet Propulsion Labs, The Rocket Company, SpaceX, Blue Origin, United Launch Alliance, and the Aerospace Corporation.

Organizations with safety-management systems. The airline group included those who work for an airline with an SMS as the formal safety protocol. Participants in the study included pilots, flight attendants, and members of staff and management. An assumption was made that each of participant had knowledge and experience in SMS components. Experience was defined as working in an SMS environment. Airline individuals who were sent survey invitations worked at American Airlines, Southwest Airlines, United Airlines, and Delta Air Lines.

Social media. The acceptance of social media in higher education research has grown in recent years (Al-Qaysi, Mohamad-Nordin, & Al-Emran, 2020; Gruzd, Staves, & Wilk, 2012; Rowlands, Nicholas, Russell, Canty, & Watkinson, 2011). However, one concern with the use of social media in conducting research was the sizable time requirement needed to gather response data (Gruzd et al., 2012). The social-media platforms of LinkedIn and Facebook, as well as direct email, were used to augment the survey data for this research. Both social media platforms allowed for the specific selection of individuals who met the experience criteria necessary for the survey. An IRB-approved introduction letter was used with a URL link to the Qualtrics survey site shown in Appendix D. Targeted selections of survey participants lowered the opportunities for testing-bias from unqualified individuals.

Power analysis for sample size. A power analysis for multivariate analysis of variance with two levels and two dependent variables was conducted in G*Power to determine sufficient sample size for the research with values of $\alpha = .05$, a power of 0.95, and a large effect size ($f^2 = 0.962$; Faul, Erdfelder, Buchner, & Lang, 2013). Based on the assumptions mentioned previously, an acceptable sample size was calculated to be $|n = 24|$. The details of the power calculation appear in Appendix E. Kline (2015) stated that 10 to 20 participants per parameter was a good indication of adequate power in the sample size.

Demographic questions. Two demographic questions were used as independent variables. The first question inquired about the role with which the participant identified in the organization. The second asked the length of time the participant had been in the industry. The surveys were used in separate industries with different organizational structures or management levels. A broadly worded question was used to capture the participant's understanding of the two questions. The survey question measuring participant years in the industry was designed to ascertain the length of time in the industry rather than the organization. These questions offered further insights into how these variables may have affected the dependent variables in the study.

Survey Instrument

A survey instrument was used to measure the discussed variables (see Appendix F). All questions used a 7-point Likert-style scale (1 = strongly disagree; 7 = strongly agree). An odd number of answer choices was used to allow the survey taker to make a natural choice in their selection (Heiberger & Robbins, 2014; Pimentel, 2010). An exception were the demographic questions, which used a designed measurement specific to the information being gathered. Cronbach's α was used to measure the reliability of the scales. A value of $\alpha > .70$ was used to measure the reliability of the variables used in the study (Field, 2018; Warner, 2012).

Safety management system surveys. Stolzer et al. (2018) published a survey developed for the FAA to measure the effectiveness of SMS in organizations. The questions asked participants to respond using a Likert-type scale about their understandings of the SMS elements of safety policy, safety-risk management, safety assurance, and safety promotion. An SMS had been instituted in these organizations for longer than 12 months before participants took part in the survey. The published statistical analysis from the Stolzer et al. survey resulted in the values of comparative fit index (CFI) = 0.96 and root meant square error of approximation (RMSEA) = 0.05. These results show strong goodness-of-fit for the survey. These SMS questions with the addition of one question from Adjekum (2017) were the base questions used by the Delphi group to create the SMS attribute-based questions used in this study. A letter of agreement from the publisher is found in Appendix G.

High-reliability theory. The SOS was developed by Vogus and Sutcliffe (2007) based on the attributes of HRT. This survey was designed to measure the recognition of HRT attributes through mindfulness of preoccupation with failure, reluctance to simplify operations, sensitivity to operations, commitment to resilience, and deference to expertise of nurses in medical organizations. The published SOS survey reported excellent goodness of fit across these three indices (CFI = 0.964, incremental fit index = 0.964, RMSEA = 0.05) and a Cronbach's α of .88 (Vogus & Sutcliffe, 2007). The survey has been translated into various languages and further analyzed for validation (Ausserhofer, Schubert, Blegen, De Geest, & Schwendimann, 2013).

Two HRT questions were modified to fit the target research participants. The preoccupation with failure question—"when giving report to an oncoming nurse, we usually discuss what to look out for"—was substituted with "the organization has a good 'roadmap' of each other's talents and skills." Additionally, the word "patient" was removed from "when a patient crisis occurs, we rapidly pool our collective expertise to attempt to resolve it." A CFA was conducted. The results of a CFA indicated a single factor for the nine questions. Table 5 shows a list of the factor matrix results for the HRT questions in the study. These HRT questions resulted in Kaiser–Meyer–Olkin = 0.83 (meritorious) which indicated adequate sampling and a Cronbach's α = .87 value resulting in good internal consistency. A letter of agreement from the publisher is found in Appendix H.

Table 5

High Reliability Theory Factor Matrix

High reliability theory questions	Factor
Preoccupation with Failure	0.74
Preoccupation with Failure	0.63
Reluctance to Simplify	0.58
Sensitivity to the Operation	0.65
Sensitivity to the Operation	0.59
Commitment to Resilience	0.65
Commitment to Resilience	0.68
Deference to Expertise	0.70
Deference to Expertise	0.65

Note. Extraction method: Principal axis factoring, 1 factor extracted. 5 iterations required.

The SOS questions and the adjustment made to the HRT questions for this study are listed in Table 6.

Statistical Analysis

Various test statistics were used for analysis related to achieving the research objectives and answering the research questions. Significance in mean attributes of perceptions on items was assessed using independent *t*-test and analysis of variances (ANOVA). Structural equation modeling (SEM) measurement model (MM) was used to determine the predictive relationships between measured variables and the overarching construct of SMS. The SEM-MM was also used to assess the goodness-of-fit of measurement models from the collected data.

Table 6

Safety Organizing Scale and High Reliability Theory Questions

HRT dimension	Safety organizing scale questions	HRT questions used in research
Preoccupation with Failure	When giving a report to oncoming nurses, we usually discuss what to look out	The organization has a good "roadmap" of each other's talents and skills
	We spend time identifying activities we do not want to go wrong	We spend time identifying activities we do not want to go wrong
Reluctance to simplify interpretation	We discuss alternatives as to how to go about normal work activities	We discuss alternatives as to how to go about normal work activities
Sensitivity to operations	We have a good "map" of each person's talents and skills	We have a good "map" of each person's talents and skills
	We discuss our unique skills with each other so that we know who has relevant specialized skills and knowledge	We discuss our unique skills with each other so that we know who has relevant specialized skills and knowledge
Commitment to resilience	We talk about mistakes and ways to learn from them	We talk about mistakes and ways to learn from them
	When an error happens, we discuss how we could have prevented them	When an error happens, we discuss how we could have prevented them
Deference to expertise	When attempting to solve a problem, we take advantage of the unique skills of our colleagues	When attempting to solve a problem, we take advantage of the unique skills of our colleagues
	When a patient crisis occurs, we rapidly pool our collective expertise to attempt to resolve it	When a crisis occurs, we rapidly pool our collective expertise to attempt to resolve it

Note. From The Safety Organizing Scale: Development and Validation of a Behavioral Measure of Safety Culture in Hospital Nursing Units, by T. J. Vogus & K. M. Sutcliffe, 2007, *Medical Care, 45,* p. 48. https://doi.org/10.1097/01.mlr.0000244635.61178.7a

Robust technique in the form of 5000 bootstrap samples with Bias Corrected Accelerated (BCa) confidence interval (95%) was used for the SEM and predictive analysis. This mediated the potential violations of the assumptions of linearity due to the relatively small sample size (Fields, 2018). The results of the qualitative survey were downloaded from the Qualtrics software under the University of North Dakota license. Statistical analysis was conducted using IBM SPSS (v. 26) and IBM AMOS Graphic (v.

23) software. *A priori* statistical significance was set at .05 for the ANOVA and independent *t*-test.

The data from the responses were loaded into the SPSS AMOS software and a first-order CFA was conducted to determine the strength of relationship between items and the explanatory factors. This approach graphically displayed the predictive relationships between items and latent constructs. Once a good fit was determined, averaged variance extracted (AVE) reliability and construct validity were calculated for the items that loaded for the model. The following model-fit indices were analyzed: chi-squared (χ^2), RMSEA, CFI, and Tucker–Lewis Index (TLI). An RMSEA < 0.05 would indicate a good fit; $0.05 \leq$ RMSEA ≥ 0.10 a moderate fit; and < 0.10 a bad fit (Hu & Bentley, 1998). CFI > 0.95 indicated a great fit, > 0.90 a traditional fit, and > 0.80 indicates acceptable fit. For TLI, values greater than 0.95 implied a good model fit (Hooper, Coughlan, & Mullen, 2008). An AVE > 0.50 and a CR > 0.70 is considered acceptable (Hair, Black, Babin, & Anderson, 2010).

CHAPTER 4

RESULTS

There were two goals for this research study: to establish a method to introduce a SMS as a standard formal safety protocol for commercial space organizations and to determine whether HRT attributes exist in an airline SMS environment. The following questions addressed the research goals:

1. What is the validity and reliability of a measurement instrument that measures the overarching concept of SMS in aviation and commercial space organizations?
2. What are the differences in the mean responses of participants from commercial space organizations without an SMS and airlines with an SMS on factors underlying SMS?
3. What are the differences in the mean responses of participants from commercial space organizations without an SMS and airlines with an SMS on factors underlying HRT?

Statistically significant differences in mean values of the SMS and HRT elements recognized by participants were assessed using independent *t*-test and one-way ANOVA. The SEM-MM measured the variables of the overarching construct of SMS. Normality in the data was assumed using a robust corrected accelerated bootstrap at the 95% confidence level.

Survey Responses

Descriptive statistics were conducted including mean, standard deviation, standard normal error of the mean (using SEM), test for normality (skewness and kurtosis), and histograms with normal curves. Table 7 shows the commercial space and airline survey-participant demographic results.

Table 7

Survey Subject Demographic Results

	Commercial space		Airlines	
	Number	Percentage	Number	Percentage
Years in industry				
0 to 5	7	12	2	2
5 to 10	3	5	3	3
10 to 15	9	15	5	5
15+	40	68	79	90
Role in the organization				
Nonsupervisor	25	42	37	42
1st-level supervisor	9	15	32	36
Manager	10	17	16	18
Senior manager	15	25	3	3

The majority of participants (68%) have been in the commercial space industry for 15 years or more. Approximately 20% of participants had been in the industry under 10 years. More than 40% of those surveyed identified their position as being in a nonsupervisory role. These data suggest that commercial space may have newer members in the industry, supporting the notion of growth. Of note, however, was that approximately 25% of responders identified themselves as senior managers. It was conceivable that the organizational structure in commercial space had a higher number of senior managers per number of employees. It was also possible that a high percentage of the survey participants were senior managers.

The data for the airline group suggested that a larger percentage of participants skewed toward the higher end (90%) of years worked in the industry (15 or more years). These results indicated that those working at a major airline in the United States had been working in the industry for longer than those in the commercial space industry, suggesting an experienced workforce. A higher number of years in the industry may lead to a stronger understanding of SMS in the group. Results indicated that 78% of respondents identified as nonsupervisory or first-level supervisors for the airline group. Senior managers and managers comprised 21% of the group, which may include chief pilots, department leads, or other levels of upper management.

Research Question 1

Items relating to the modified SMS-attribute questions used in the psychometric factor Organization Safety Attribute Awareness Survey derived from the Delphi group using the Stolzer et al. (2018) survey as base questions. The following model fit indices were analyzed via IBM SPSS (v. 26) and IBM AMOS Graphic (v. 23): chi-squared (χ^2), RMSEA, CFI, and TLI. Figure 12 depicts a best fit model produced through the SEM-MM method. The individual SMS elements (safety policy, safety risk management, safety assurance, and safety promotion) best fit models and maximum likelihood estimates of the SMS variable including standard regression weight estimates (SRW Est), standard error (S.E.), beta (β) appear in Table 8. The SEM resulted in an χ^2 (2, 151) = 6.59, $p < .05$, suggesting a strong model. The RMSEA = 0.023, TLI = 0.958, and CFI = 0.992 also confirmed a strong model fit. The individual SMS elements max likelihood estimates are found in Appendix I.

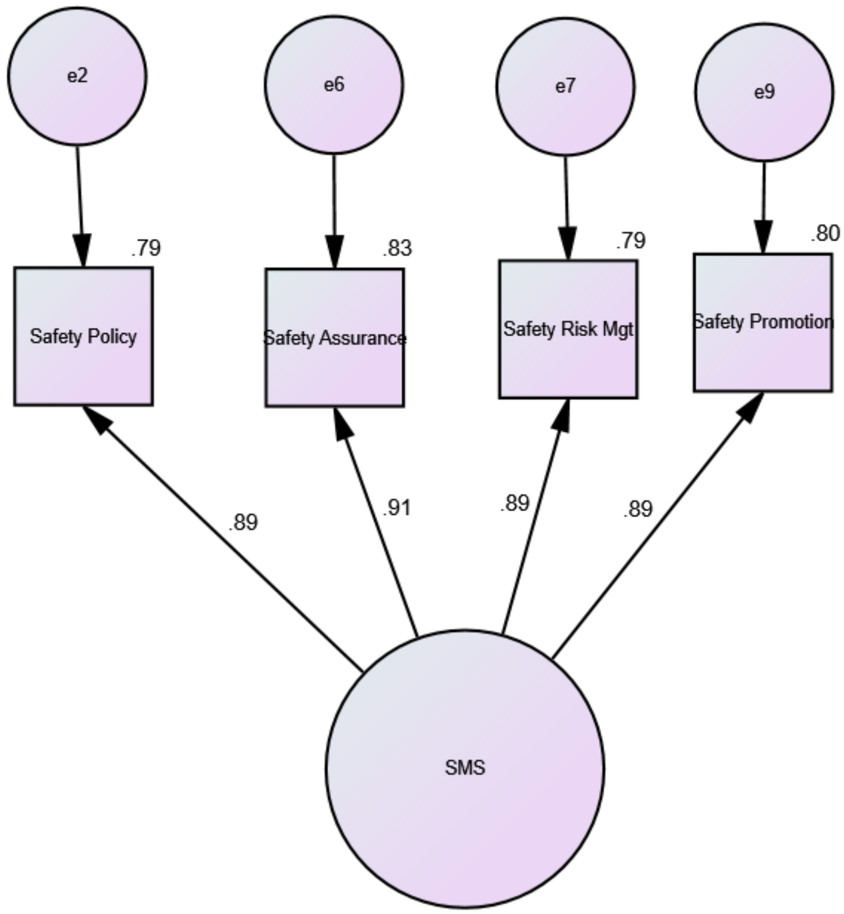


Figure 12. Structural equation modeling measurement model of relationships of safety-management-system elements.

Table 8

Maximum Likelihood Estimates of Safety Management System Variables Using Confirmatory Factor Analysis-Path Analysis

Variable	SRW Est	*S.E.*	*p*	*β*	R^2	X^2	TLI	CFI
Safety Policy	0.89	0.77	0.008	0.89	0.79	9.59	0.88	0.98
Safety Risk	0.90	0.79	0.022	0.89	0.79	7.65	0.92	0.98
Safety Assurance	0.89	0.83	0.007	0.91	0.83	9.90	0.91	0.98
Safety Promotion	0.89	0.79	0.370	0.89	0.79	5.39	0.99	0.99

Convergent validity of the model elements was determined by calculating the AVE using the formula:

$$\text{AVE} = \frac{\sum_{i=1}^{n} \lambda_i^2}{n}.$$

Furthermore, the CR using the formula:

$$\text{CR} = \frac{(\sum \lambda_i)^2}{(\sum \lambda_i)^2 + (\sum \epsilon_i)}$$

was used for the model. The AVE is a validity measurement of the levels of variance captured during modeling due to measurement error assessing the discriminate validity of the model (Hair et al., 2010). An Excel spreadsheet was used to calculate the AVE and CR data from the structural equation final mode. Table 9 shows the computed AVE threshold > 0.50 and the CR threshold > 0.70 results for the four elements of safety policy, safety risk management, safety assurance, and safety promotion. These indicated good validity and reliability for the questions used in the final model (Hair et at., 2010).

Table 9

Average Variance Extracted and Composite Reliability for the elements of Safety Management Systems

SMST	Average variance extracted	Composite reliability
Safety policy	0.64	0.88
Safety Risk	0.69	0.90
Safety assurance	0.73	0.91
Safety promotion	0.68	0.91

Note. SMST = Safety management system theory.

The results of the SEM-MM demonstrated acceptable loading with χ^2, RMSEA, TLI, CFI, AVE, and CR values. Those SMS questions that showed high loading values for SMST variables were used to create the survey instrument. Possessing the ability to determine which SMS elements require additional emphasis in an organization may be helpful to senior management to more efficiently implement an SMS program. The researcher hoped this survey would offer the FAA/AST accurate results to ascertain effective future implementation of SMS in the industry. Dependable survey results may also assist commercial space companies to determine which current safety elements will require additional resources accurately. The FAA/AST may also survey commercial space companies to offer assistance with near-term volunteer implementation of SMS. Organizations may incorporate the results of this survey to make internal safety adjustments more quickly and with greater accuracy.

Results from Research Questions 2 and 3

The mean values of the elements of SMST were calculated from the questions identified during the first-order CFA using the SEM approach (maximum likelihood estimation). Mean values were calculated from the HRT questions adopted from Vogus and Sutcliffe (2007). Separate independent sample *t*-tests were conducted to examine whether statistically significant differences in mean responses for the elements existed between the airlines and commercial space groups (see Appendices J and K). The data met normality assumptions through the rigorous corrected accelerated bootstrapping at the 5,000 iterations level with a confidence interval (CI) of 95%. Cohen's *d* was calculated with the following formula:

$$\text{SDpooled} = \sqrt{[(\text{SD12}+ \text{SD22}) / 2]},$$

$$d = \text{M1}–\text{M2}/\text{SDpooled}.$$

According to Cohen (1988), $d \geq 0.2$ indicates a small effect size, $d \geq 0.5$ indicates a medium effect size, and $d \geq 0.8$ indicates a large effect size for variables, in this case SMST.

Research Question 2

The results found in Table 10 represent the differences between the groups' SMS mean values. These results suggested that respondents in the airline group exhibited an excellent understanding of the questions asked in the SMS-attribute survey. The descriptive statistics indicated that 90% of airline respondents had more than 15 years in the industry. These data suggested that the airline group provided a good indicator of acceptance of SMS attributes in the survey questions.

Table 10

Safety Management System Theory Elements Between-Group Statistics

Element	Type	*N*	Mean	Std. dev.	Significance	Cohen's *d*
SafetyPolicy	airlines	91	6.00	1.06		
	comm space	61	5.86	0.78	.381	
SafetyRiskMgt	airlines	91	5.89	1.13		
	comm space	62	5.88	0.77	.946	
SafetyAssurance	airlines	91	5.91	1.13		
	comm space	62	5.51	1.03	.027	0.37
SafetyPromotion	airlines	90	5.69	1.13		
	comm space	60	5.69	0.93	.990	

The overall outcomes show similar mean values between the airline and commercial space groups, excluding the safety assurance element. The difference in survey responses for safety assurance was statistically significant, $t(151) = 2.23$, $p = .027$, $d = 0.37$ denoting a small effect size. This result indicated that airline respondents had a higher recognition of assurance than commercial space participants. However, overall results suggested roughly equal response values between members of the airline and commercial space groups. The similar outcomes suggested two important matters. First, the results indicated that the SMS characteristic survey to answer Research Question 1 was suitable in determining SMS attributes based on the higher mean values from the airline group. Second, the commercial space group appeared to identify with the SMS attributes at similar levels when compared to the airline group. These results suggest a baseline understanding of the SMS attributes by the group.

The 95% confidence interval error bars appear in the Figure 13 overlap suggesting that large differences in mean values between groups were not prevalent for the SMS elements. Figure 13 further represents that the two groups responded to the SMST attributes at comparable levels (aligned with Field, 2018).

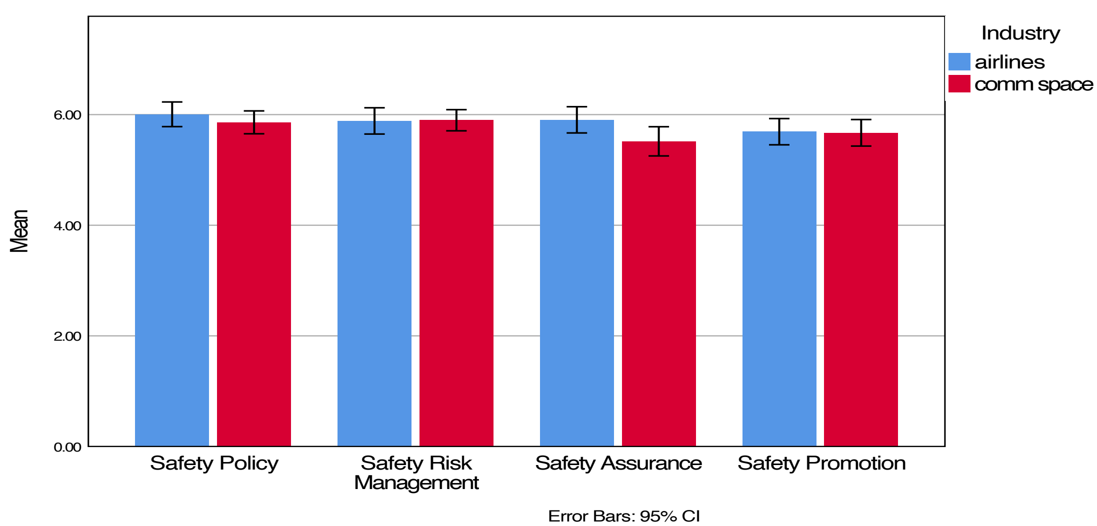


Figure 13. Comparison of safety management system theory mean values with 95% confidence interval error bars.

Furthermore, the airline participants' high results implied that the SMS survey accurately tested for elements of an SMS. Additionally, the similar response levels from the commercial space group may indicate that SMS elements exist, in some form, in the organizations. The independent-sample test full results appear in Appendices E and F.

Figure 13 represents the mean values for the four SMST elements with error bars for direct comparison between the airline and commercial space groups. Safety assurance resulted in the only statistically significant difference in mean values between the two groups. Cohen's *d* suggested a small effect on the mean difference between the airline and commercials space groups. Safety policy, safety risk management, and safety promotion did not have statistically significant differences between groups. Figure 13 depicts comparable high mean values of SMS elements between the two groups. A plausible explanation for this is that the commercial space group recognized the SMS features as universal formal safety-system attributes. It was also likely that commercial space participants responded positively to the questions in general. The data supported the notion that the testing for SMST was possible in organizations without an active SMS. These results may offer assistance in the future testing of SMS in commercial space organizations through the establishment of baseline values used as a comparison for organizations in the commercial space industry.

Safety Management System Theory Hypotheses Testing

> There is no difference in mean value of items that measure safety policy among commercials space organizations without SMS and airlines with an SMS (H_{0a}).

No statistically significant differences emerged in mean values between the airline group and the commercial space group regarding safety policy. This resulted in a failure to reject the null hypothesis. In an SMS, safety policy contains the structure of the overall formal protocol. It lists many of the required elements and practices of the SMS. This concept appears to be ubiquitous to other safety systems. Therefore, it is understood by commercial space respondents who were not familiar with an SMS or the specific attributes of SMST.

> There is no difference in mean value of items that measure safety risk management among commercials space organizations without an SMS and airlines with an SMS (H_{ob}).

Results indicated no significant differences emerged in mean values between groups on safety risk management, indicating acceptance of the null hypothesis. Safety risk management appears to be a universal concept in operations with a degree of risk. The mean results suggested that this concept was easily identifiable for the commercial space group as a standard component of a formal safety protocol.

> There is no difference in mean value of items that measure safety assurance among commercials space organizations without an SMS and airlines with an SMS (H_{oc}).

The results indicated that a statistically significant difference emerged between the mean values for the airline and commercial space groups on safety assurance $t(151) = 0.07$, $p = .025$, $d = 0.37$. These results further indicated a small effect size. Therefore, the null hypothesis was rejected. Safety assurance included methods to determine the effectiveness of the SMS. Although the specific SMST-attribute question results from the commercial space group were lower than those of the airline group, the concept of measuring a safety program's effectiveness was recognized at similar levels by both groups.

There is no difference in mean value of items that measure safety promotion among commercials space organizations without an SMS and airlines with an SMS (H_{0d}).

Results indicated no significant differences emerged in mean values between groups on safety risk management, indicating a failure to reject the null hypothesis. The SMS element of safety promotion encompasses safety-protocol training and communication of operations information. The intent of this element is to foster a positive safety culture. Results suggested these functions may be universal and known to respondents from the commercial space group.

SMS Survey Summary

Survey results for the airline group showed high mean levels for the four SMS elements of safety policy, safety risk management, safety assurance, and safety promotion. Airline respondents appeared to have good familiarity with the four elements of an SMS and responded accordingly to the survey questions. For this research, the airline group helped validate the SMS survey question and created a baseline measurement used for comparison with the commercial space group. Three of the four SMS elements did not have significant differences between the airline and commercial space groups. Results suggested that the commercial space subjects responded at similar levels to the airline groups for these elements. Additionally, the attributes of SMST appear to be recognizable and acceptable to the commercial space group.

Further, the mean values for safety assurance did not show a difference larger than one standard deviation. This difference value may indicate that commercial space participants responded, in general, at a roughly similar level to the airline group.

Commercial space respondents may have a predisposition to acceptance of the elements indicated in an SMS, given the current safety protocols in place in their organizations.

Research Question 3

Survey responses for HRT questions on preoccupation with failure, reluctance to simplify, and sensitivity to the operations were statistically significant between the two groups. Table 11 illustrates the HRT group-mean statistics for comparison.

Table 11

High-Reliability Theory Element Between Group Statistics

Element	Type	Mean	Std. Dev	Significance	Cohen's *d*
Preoccupation with failure	airlines	5.97	0.97		
	commercial space	5.32	1.23	.000	0.59
Reluctance to simplify	airlines	5.89	1.13		
	commercial space	5.19	1.42	.001	0.61
Sensitivity to the operation	airlines	4.95	1.22		
	commercial space	4.45	1.48	.023	0.48
Commitment to Resilience	airlines	6.33	1.03		
	commercial space	6.16	0.93	.301	
Deference to Expertise	airlines	5.89	1.07		
	commercial space	5.66	1.24	.225	

The mean value differences between the airline group and the commercial space group for preoccupation with failure resulted in a statistically significant value of $t(151) = 3.65$, $p < .00$. Cohen's $d = 0.78$, which denoted a medium effect size. The airline group reacted to preoccupation with failure at a higher mean level than the commercial space group. HRT was not a formal safety protocol and not something members of the groups may have recognized. Regardless, each group had responses that suggested the HRT element was imbued in the existing culture. The potential failure awareness captured in the HRT survey questions resonated with both groups.

Similarly, the data showed differences in values between the two groups for reluctance to simplify, $t(151) = 3.82$, $p < .00$. Cohen's $d = 0.61$ denoted a medium effect size. The HRT survey question, "we discuss alternatives as to how we go about our normal work activities," may not be an element that had shared significance between the groups. The results suggest that the airline group may have operational latitude in job tasks that the commercial space group does not. Reluctance to simplify had the second-lowest response mean value for commercial space. The results suggest that the nature of commercial space operations may not allow for any deviation for standard protocols.

Additionally, sensitivity to the operations had a statistically significant difference in mean values between the two groups $t(151) = 2.29$, $p = .23$. Cohen's $d = 0.48$, which is a small effect. In contrast, sensitivity to operations has the lowest value collectively. This HRT element involved a holistic operations view that measures the interaction of the members, external influences, with the sharing of information in the organization. The results suggest that discussing differences in individual skill sets was not a common practice for either group. Ambiguity in the wording may also have influenced lower results. The airline and commercial space groups may comprise somewhat homogeneously trained individuals. The questions delved into concepts that the groups appear not to have identified with given possible equal levels of education and experience.

The remaining two HRT attributes, commitment to resilience, and deference to expertise, did not have statistically significant differences between the groups. Of interest were the values for commitment to resilience. This HRT characteristic resulted in the highest mean values of the five HRT attributes for both groups. Results suggested that participants in both groups identified with the concepts of discussing errors and methods for error prevention.

Deference to expertise had the second collective highest mean values for the groups. Both appeared to identify with the concept of advocating for consultation with an expert during problem-solving. Additionally, collaborative problem solving in the group seemed to be an HRT element with measured understanding.

The HRT element mean values with 95% confidence interval error bars appear in Figure 14 for comparison between the airline and commercial space groups. Results confirmed that preoccupation with failure, reluctance to simplify, and sensitivity to the operation had statistically significant differences between mean values for the airline and commercial space group respondents.

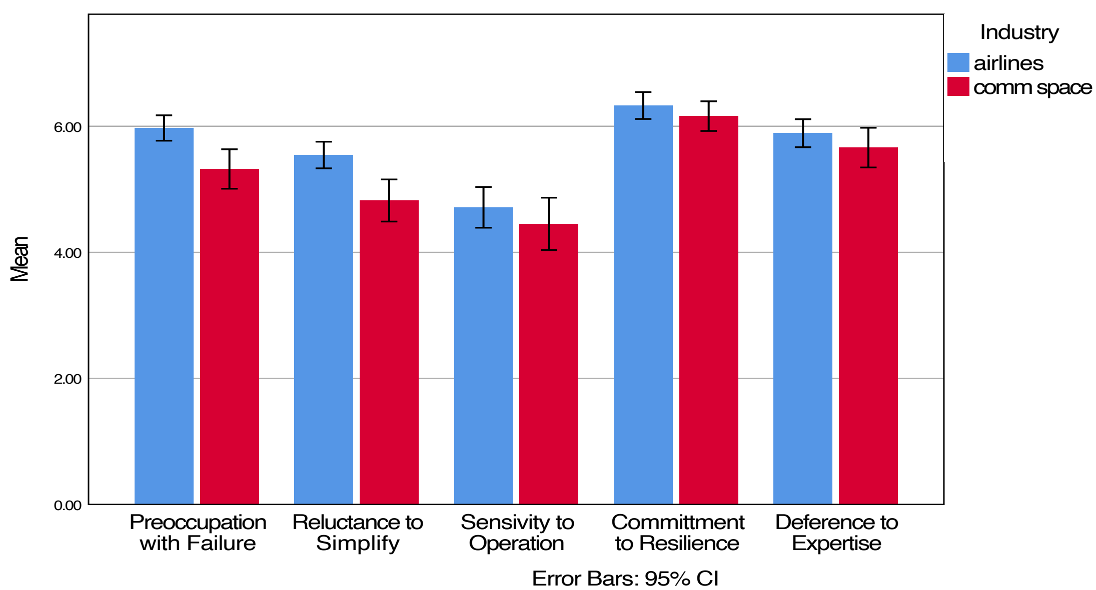


Figure 14. Comparison of high reliability theory mean values with 95% confident interval error bars.

Of note, however, are similarities in overall results, suggesting the two groups view HRT elements in roughly the same manner. This impression may suggest that high-risk operation-based organizations equally embrace HRT attributes without specific knowledge of the components. For the airlines, the results indicated that HRT attributes can exist in an SMS environment.

High reliability theory hypotheses results.

> There is no difference in the mean values of items that measure preoccupation with failure among commercial space organization without an SMS and airlines with an SMS (H_{0e}).

Results indicated a significant difference emerged in mean values between groups on preoccupation with failure ($t[151] = 3.65$, $p < .001$), $d = 0.59$. Consequently, the null hypothesis was rejected. This element encompassed the requirement for members to be attentive to operational anomalies. Despite a difference in mean values, each group responded with high overall values, suggesting each group collectively accepted this HRT element.

> There is no difference in the mean values of items that reluctance to simplify among commercial space organization without an SMS and airlines with an SMS (H_{0f}).

Results indicated a significant difference emerged in mean values between groups concerning a reluctance to simplify the operation ($t[151] = 3.82$, $p < 0.00$), $d = 0.61$. Therefore, the null hypothesis was rejected. Reluctance to simplify refers to the ability to challenge an operational status quo and interrogate current operating procedures seeking any weaknesses. The results, although statistically different between groups, suggested the groups identified with the notion of persistent vigilance.

> There is no difference in the mean values of items that measure sensitivity to the operation among commercial space organization without an SMS and airlines with an SMS (H_{0g}).

Results indicated a significant difference emerged in mean values between the groups with sensitivity to the operation. The null hypothesis was rejected. Of note are the low collective mean responses for each group. Sensitivity to the operations revolves around how processes are functioning. The data suggested neither group responded to this HRT element. However, this characteristic may seemingly be apropos of many high-risk operations. A possible explanation includes participants' understanding of the wording of the questions.

> There is no difference in the mean values of items that resilience in the operation among commercial space organization without an SMS and airlines with an SMS (H_{oh}).

Results indicated no significant difference emerged in mean values between groups on the commitment to resilience in operations. Therefore, there was a failure to reject the null. Resilience includes the actions of the organization before, during, and after an event. Both groups responded at the highest level to this HRT concept.

There is no difference in the mean values of items that measure deference to expertise among commercial space organization without an SMS and airlines with an SMS (H_{0i}).

Results indicated no significant difference emerged in mean values between groups on deference to expertise resulting in a failure to reject the null hypothesis. Results indicated that both groups recognized this HRT characteristic. Participants recognized the idea of turning to an individual who has higher knowledge during times of need.

HRT survey summary. Results suggested the airline respondents identified with the HRT attributes of preoccupation with failure, reluctance to simplify, commitment to resilience, and deference to expertise at higher levels that would indicate acceptance of the concepts. The three factors had values above 5.88 on a 7.0 Likert-type scale. Sensitivity to the operation had the lowest level of recognition.

HRT attributes were not principles in which the two groups had known backgrounds or training. Results suggested that the airline and commercial space industries recognized HRT characteristics at roughly the same frequency. This may indicate similar patterns of understanding with operations that encompass a level of risk.

Demographic Hypotheses H_{0j}–H_{0m}

A one-way ANOVA was conducted to compare mean values for the airline and commercial space groups for management level and time in the industry. All data were assumed normally distributed using corrected accelerated bootstrap at 5,000 iterations with the CI 95%.

There is no difference in the mean values of perception of SMST in terms of the level of management in the industry in the test groups (H_{0j}).

No statistically significant effects emerged from the level of management, resulting in a failure to reject the null hypothesis. Results suggested that the level of management role was not statistically significant for SMST elements. Both groups responded to SMST survey questions at a similar level. The management role was not an indicator of acceptance or rejection. The higher numbers of nonmanagers may skew these results based on those who participated in the survey. These results may have also indicated that SMST elements were accepted regardless of role in the organization.

There is no difference in the mean values of perception of SMST in terms of the length of time in the industry in the test groups (H_{0k}).

The results did not indicate a statistically significant effect on the groups resulting in a failure to reject the null hypothesis. The length of time did not affect response levels in answering SMST questions. SMS elements were viewed in the same fashion regardless of time in the industry.

There is no difference in mean values of perception of HRT in terms of the management role in the organizations in the test groups (H_{0l}).

Results indicated two statistically significant effects emerged in mean differences. The null hypothesis was rejected. The first significant effect was sensitivity to the operation, $F(3, 152) = 3.10$, $p = .029$. The post hoc pairwise comparison did not indicate a significant effect level among the roles of management.

The second statistically significant effect was with deference to expertise $F(3, 152) = 3.11$, $p = .028$. A post hoc Tamhane pairwise comparison (used here for unequal size groups) indicated a significant influence ($p = .003$) between senior manager and those in nonsupervisory roles. This result suggested that senior managers may be more sensitive to HRT characteristics than nonsupervisory personnel.

> There is no difference in mean values of perception of HRT in terms of length of time in the industry in the organization in the test groups (H_{0m}).

No statistically significant differences emerged between the groups in the industry. Therefore, there was a failure to reject the null hypothesis. The results suggested that the length of time participants had been in their respective sectors did not affect their recognition of HRT attributes.

SMST and HRT

The researcher selected an acceptable mean value above 4.0 to depict a positive reaction to the components. This value represented a mean higher than “neither agree nor disagree” and was greater than the average of 3.5 for a 7-point Likert-style scale. All SMS mean values for the commercial space group resulted in outcomes above 4.00. These mean value results, coupled with the statistical analysis, suggested SMS attributes may be safety fundamental elements that the commercial space respondents recognized and acknowledged.

The highest mean value for the commercial space group was safety risk management (5.88), and the lowest was safety assurance (5.51). The SMS mean values for the commercial space group were similar to the airline group’s results. A comparison of the airline group means indicated a strong acceptance of the SMS attributes with mean values above 5.60. Coupling these mean results from the airline group with AVE values (> 0.50) and the CR values (> 0.70) from the SEM-PA analysis suggested this survey instrument can determine the existence of SMS elements in organizations. Table 12 depicts the means and standard deviations for each of the SMST and HRT elements for commercial space and airline groups. The results from using this survey may offer assistance to the FAA/AST in bringing SMS to commercial space companies in the future. The use of study results provides increased efficiencies of implementation by determining which SMS elements require additional focus when implementing an SMS as a formal safety protocol.

Table 12

Mean Value Comparison for Safety Management System theory and High Reliability Organization

Element	Comm space	Std. deviation	Acceptance level	Airline	Std. deviation
Safety management system theory					
Safety policy	5.86	0.78	4.00	6.00	1.06
Safety risk	5.88	0.77	4.00	5.89	1.13
Safety assurance	5.51	1.03	4.00	5.91	1.13
Safety promotion	5.69	0.93	4.00	5.69	1.13
High reliability theory					
Preoccupation with failure	5.32	1.23	4.00	5.97	0.96
Reluctance to simplify	5.19	1.42	4.00	5.89	1.13
Sensitivity to the operation	4.45	1.48	4.00	4.95	1.22
Resilience in the operation	6.33	1.02	4.00	6.16	0.92
Deference to expertise	5.66	1.24	4.00	5.89	1.06

Note: A value above 4.0 was considered to denote acceptance of the attribute.

HRT mean values of the airline-group surveyed participants seen in Table 12 revealed mixed results. The highest mean value was resilience in operations (6.16) and the lowest was sensitivity to the operation (4.71). High acceptance of a commitment to resilience may stem from the repetitive risky nature of the airline industry. Operational mistakes may cause incidents or accidents to occur. The HRT questions used for resilience to the operation focused on errors, how to learn from, and prevent them in future operations. Results suggested the airline group identified with this concept, making dynamic decisions to small portions of overall operations based on a continuous stream of new data.

An example may be the control inputs that a pilot-in-command makes to flight controls during routine landings. The pilot needs to make constant micro adjustments to compensate for changing conditions such as wind, weather, and traffic conditions, whereas the respective low values for reluctance to simplify may be explained by the sampling of participants in the airlines or the wording of the survey questions used for this HRT element. This attribute seems to conflict with reluctance to simplify, as both HRT attributes imply an ability to monitor, measure, and adjust to the active operation.

Commercial space and airlines are sensitive to failures. Commercial space operations, whether rocket launches or satellite manufacturing, require large capital expenditures that demand high levels of competency and resilience. Qualities such as these are necessary to continue an endeavor that has considerable potential economic and human risks to achieve success. However, these hazards are at a much higher level than the airlines, which have matured over time. The overall results of the analysis suggested that commercial space participants recognized the attributes of an SMS. Additionally, the study results indicated that airline group participants responded to the HRT attributes at varying positive levels.

Summary

The first purpose of this study was to determine whether the attributes of SMST exist in commercial space organizations. To that end, a subset of SMST attributes, i.e., safety policy, safety risk management, safety assurance, and safety policy, was found in current organizations. As a consequence, as the industry develops, the implementation of SMS in commercial space can be reasonably expected to be facilitated by quantifying the presence of these attributes.

The second purpose was to determine whether characteristics of HRT can be found in extant SMS organizations in the airline industry. This study showed that the following qualities could be found in such organizations: (1) resilience in the operations, (2) preoccupation with failure, (3) reluctance to simplify, (4) deference to expertise. This finding expands the existing body of knowledge regarding HRT, proving that these attributes were seen in an organization without specific HRT instructions for the members.

CHAPTER 5

CONCLUSIONS AND FUTURE RESEARCH

An ESMM design was used in this research project. Three areas required emphasis. The first was to validate a survey instrument used to identify SMST attributes for commercial space organizations. The second was to evaluate whether employees of commercial space organizations recognized the attributes of a SMS. The third area of focus was to determine whether HRT qualities existed among members of the airlines. In this study, the researcher attempted to create benchmark levels of understanding of SMST and HRT in the testing groups. GT was used in the literature review, in coding SMS attributes for survey questions, and to search for existing theory to develop.

Robust technique in the form of 5000 bootstrap samples with Bias Corrected Accelerated (BCa) confidence interval (95%) was used for the SEM and predictive analysis. SEM allowed for adjustments to the SMS element questions resulting in the final study. The outcome model had validity and reliability above the benchmark values of AVE > 0.70 and CR > 0.50. Best-fit modeling produced the final model, testing the four elements of SMS. These questions produced a model resulting in a good model fit.

The combination of modified HRT questions published by Vogus and Sutcliffe (2007), the SEP-PA SMS questions plus two demographic questions created the 35 questions comprising the Organizational Safety Attribute Awareness Survey. Care was taken to keep the time required to complete the survey to between 12 and 16 minutes to maximize survey-completion rates. Identical surveys were sent electronically to two separate groups and were available for 3 weeks. The total sample size was of 154 participants (60 commercial space industry subjects and 94 airline industry subjects).

Comparisons of individual mean values were conducted between groups, as well as comparisons of the combined data. A group-acceptance value of 4.0 was used to indicate overall recognition of SMS or HRT elements.

Safety Management System Theory

A comparison of mean values for SMS attributes was conducted between subjects from commercial space and airline groups. An independent *t*-test was used to compare the average mean values between the two groups. Safety assurance results indicated that statistically significant differences existed between the mean values of the groups. Safety policy, safety risk management, and promotion did not indicate differences between the groups. Overall, the mean values for the two groups had similarities above the preestablished acceptance level of 4.00. These results suggested that the surveyed commercial space respondents had levels of recognition of SMS elements. Future implications may include additional focused SMS attribute surveys in specific commercial space companies to streamline the adoption of an SMS as the formal safety protocol.

High Reliability Theory

Mean value comparison was conducted between airlines and commercial space organizations on understanding of HRT attributes. Independent *t*-tests were conducted to compare the averaged mean values for HRT between the groups. Results indicated that preoccupation with failure, reluctance to simplify, and sensitivity to the operation had statistically significant differences in mean values between members of the two groups. However, commitment to resilience and deference to expertise did not show a statistically significant difference in mean values.

The mean values for HRT elements surveyed in both groups had values above the established acceptance level of 4.00. This result suggested some level of acknowledgment for HRT concepts had taken place in organizations, determined during surveying. The members of the airline group had four elements (preoccupation with failure, sensitivity to operations, commitment to resilience, and deference to expertise) that showed understanding at a level above 5.0. One measure, commitment to resilience, showed the highest overall universal acknowledgment in the group. Results suggested that HRT principles exist among airline employees working in an SMS environment.

Demographic Questions

One-way ANOVA testing was conducted to determine whether time in the industry or the self-identified management role had a statistically significant impact on the dependent SMS variables of safety policy, SRM, safety assurance, and safety promotion and the HRT variables of preoccupation with failure, reluctance to simplify, sensitivity to the operations, commitment to resilience, and deference to expertise. No statistically significant differences emerged in SMS attributes for the two independent variables.

However, statistically significant differences did emerge in HRT variables related to the management role in the organization. Results indicated that the HRT element of reluctance to simplify was statistically significantly different between first-level managers and those in nonsupervisory roles. Additionally, sensitivity to the operations was also statistically significantly different between senior managers and those in nonsupervisory roles. This outcome suggested that higher level managers were more aware of HRT attributes than were nonsupervisory respondents.

Limitations

The methodology for this study provided several limitations. The first was survey testing time for the pilot study. The survey was conducted during the holiday season in December when many student pilot instructors were away. Although the test was distributed electronically with a link to take the test, the timing of the survey may have affected the number of responses. The main pilot-test groups were student instructors at a collegiate flight school and academic research center. These groups received multiple survey requests throughout the year, creating a potential survey-fatigue situation.

The ESMM is limited in that it provides a single moment in time without the ability to adjust for changes. The study was designed to compare two groups. Testing groups from two different industries for the understanding of unfamiliar theories may have been a limiting factor.

Testing two groups on aspects of HRT may not have yielded the strongest comparison for the airline group. It is conceivable that neither group was familiar with or recognized HRT attributes. That said, the calculated mean value results indicated a possible baseline understanding of most concepts.

Future Research

This study attempted to set benchmarks to detect attributes of SMST in the commercial space industry and to create a foundation on which to build. Furthermore, this study sought to establish a level of recognition of HRT attributes in the airline industry. The commercial space industry appears to be expanding with new technologies, missions, and companies entering the industry. The advent of space tourism may increase launch rates to the highest levels seen to date. Currently, airline-safety levels are at an all-time high because of the hard work of the FAA and airlines to maintain high safety levels. Constant vigilance on the part of operators and the FAA is critical to keeping these levels. This alertness will be necessary for the FAA/AST and commercial space as the growth in the industry continues. Future studies should include the FAA/AST as a research partner, forging a path for increased numbers of survey participants. Such a partnership may offer opportunities for entire organizations to participate in future studies building on this research.

Future research studies may include direct comparisons in multiple commercial space companies to determine overall organizational understandings of SMST. Using larger survey groups (commercial space and airlines) may yield a deeper understanding of how companies recognize SMST attributes. A triangulated or explanatory mixed-method study would expand on the results of this research.

A longitudinal study may follow this HRT research. A time period with the introduction of HRT elements followed by future testing may determine enhanced HRT awareness in airline groups. Measuring understanding of the HRT over time in an SMS environment may identify specific HRT elements that would help increase the current safety culture and structure. Focusing on additional HRT questions in addition to the use of the Mindfulness Organizing Scale may provide enriched reaction information. Enhanced data may come from testing at an entire organization. Institution wide testing of HRT in airlines and commercial space companies will offer detailed statistical data to formulate any augmentations to existing safety procedures and practices and enhance overall safety in the airline industry.

Summary

It was the intent of this research study to augment the collection of literature on SMST. The Delphi group output of the SMS attribute-based questions created a survey instrument targeted at uncovering understanding of SMS elements in commercial space organizations. The testing validated the survey. The results further suggested effectiveness in discerning whether the attributes exist organically in an organization. The consequences of this study furthers the discussion on SMST.

The fundamental understanding of how members of a group recognize additional safety theories will allow the management, as well as the FAA/AST, to suggest amplifications to any current safety structure in the future. The FAA/AST has no proposed SMS adoption timeline for commercial space companies to date. These data may help foster a clearer understanding of SMST among commercial space and offer a means to more quickly institute the program. The FAA is a well-established advocate of the principles of SMS. A universal understanding of how an organization's members comprehend the attributes may be important for the company and the FAA/AST in the future. An industry-standard safety-platform protocol and measurement matrix will allow for parallel assessments between companies. A common industrywide means of measuring safety may also foster increased collaborations in the industry.

Additionally, this study added an understanding of how HRT attributes may augment existing formal safety structures in the airline industry. The knowledge of the characteristics of HRT may offer airlines support for and amplification of existing safety protocols. Safety is a living, growing, evolving concept that demands constant reevaluation in companies. The tools provided by HRT may augment existing SMS formats with the introduction of the five HRT principals, along with the idea of mindful operations.

Appendix A

Safety Management System Elements

Table A1

Safety Management System Elements

Safety Policy—Establishes senior management's commitment to continually improve safety; defines the methods, processes, and organizational structure needed to meet safety goals.	• Establishes management commitment to safety performance through SMS • Establishes clear safety objectives and commitment to manage to those objectives • Defines methods, processes, and organizational structure needed to meet safety goals • Establishes transparency in management of safety o Fully documented policy and processes o Employee reporting and resolution system o Accountability of management and employees • Builds upon the processes and procedures that already exit • Facilitates cross-organizational communication and cooperation
Safety Risk Management (SRM) — Determines the need for, and adequacy of, new or revised risk controls based on the assessment of acceptable risk.	• A formal process within the SMS composed of: o Describing the system o Identifying the hazards o Assessing the risk o Analyzing the risk o Controlling the risk • The SRM process may be embedded in the processes used to provide the product/service
Safety Assurance (SA) - Evaluates the continued effectiveness	• SMS process management functions that systematically provide confidence that organizational outputs meet or exceed safety requirements • AVS SMS has a dual safety assurance focus: o AVS organizations o Product/service providers • Ensures compliance with SMS requirements and FAA orders, standards, policies, and directives o Information Acquisition

	▪ Audits and evaluations ▪ Employee reporting o Data Analysis o System Assessment o Provides insight and analysis regarding methods/opportunities for improving safety and minimizing risk o Existing assurance functions will continue to evaluate and improve service
Safety Promotion - Includes training, communication, and other actions to create a positive safety culture within all levels of the workforce	• Safety promotion activities within the SMS framework include: • Providing SMS training • Advocating/strengthening a positive safety culture • System and safety communication and awareness • Matching competency requirements to system requirements • Disseminating safety lessons learned. Everyone has a role in promoting safety

Note. From *Safety Management System for Domestic, Flag, and Supplemental Operations Certificate Holders; Final Rule,* by Federal Aviation Administration, 2015a, Washington, DC, US: U.S. Government Printing Office.

Appendix B

Internal Review Board Approval

UND UNIVERSITY OF NORTH DAKOTA

UND.edu

DIVISION OF RESEARCH & ECONOMIC DEVELOPMENT

Institutional Review Board
Tech Accelerator, Suite 2050
4201 James Ray Dr Stop 7134
Grand Forks, ND 58202-7134
Phone: 701.777.4279
Fax: 701.777.2193
UND.irb@UND.edu

November 5, 2019

Principal Investigator:	Brian Teske
Project Title:	Preparing Commercial Space Companies for Safety Management System Implementation
IRB Project Number:	IRB-201911-100
Project Review Level:	Expedited 7
Date of IRB Approval:	10/31/2019
Expiration Date of This Approval:	10/30/2020

The application form and all included documentation for the above-referenced project have been reviewed and approved via the procedures of the University of North Dakota Institutional Review Board.

The waiver of written consent has been approved under 45 CFR 46.117(c)(2).

Prior to implementation, submit any changes to or departures from the protocol or consent form to the IRB for approval. No changes to approved research may take place without prior IRB approval.

You have approval for this project through the above-listed expiration date. When this research is completed, please submit a termination form to the IRB. If the research will last longer than one year, an annual review and progress report must be submitted to the IRB prior to the submission deadline to ensure adequate time for IRB review.

The forms to assist you in filing your project termination, annual review and progress report, adverse event/unanticipated problem, protocol change, etc. may be accessed on the IRB website: http://und.edu/research/resources/human-subjects/

Sincerely,

Michelle L. Bowles, M.P.A., CIP
IRB Manager

MLB/sy

Cc: Dr. James Casler

Appendix C

Safety Management System Questions Factor Matrix

Table C1

Safety Management System Factor Matrix

	Factor
P2	0.51
P3	0.68
P5	0.80
P5.1	0.82
P6	0.86
SP8	0.84
SRM1	0.87
SRM2	0.79
SRM3	0.80
SRM4	0.86
SRM5	0.47
SA1	0.85
SA2	0.87
SA3	0.85
SA6	0.77
SA7	0.88
SA7.1	0.90
SA8	0.86
SA9	0.73
SP1	0.70
SP2.2	0.78
SP3	0.90
SP5	0.76
SP6	0.86

Note. Extraction method: Principal axis factoring, 1 factor extracted. 3 iterations required, P =Policy, SRM = Safety Risk Management, SA = Safety Assurance, SP = Safety Promotion.

Appendix D

Survey Invitation Letter

Facebook groups/LinkedIn/Direct message/email/text/personal communications Commercial Space Companies/individuals WITHOUT SMS - 2

ORGANIZATIONAL SAFETY ATTRIBUTE AWARENESS SURVEY

Hello, my name is Brian Teske, I am a Ph.D. candidate in (Space Studies/Aviation) at the University of North Dakota Odegard School of Aerospace Sciences. This letter is an invitation to participate in my dissertation research. My research deals with determining whether safety management system attributes and mindfulness/high reliability theory attributes can be detected using this survey. Additionally, my research will determine whether time and role will have a relationship in the outcome.

Here is the link to the anonymous survey. Please feel free to forward to your colleagues. Thank you. **https://und.qualtrics.com/jfe/form/SV_0D62InHsXWdxQQR**

Your frank answers will help me to determine the relationships between position in the company, time in industry, safety management system and high reliability attributes in aerospace organizations. This information will help me to craft potential safety protocol changes for commercial space and aviation companies.

If you wish further information, please contact me at brian.teske@und.edu, or you may contact Dr. Jim Casler at Casler@space.edu.

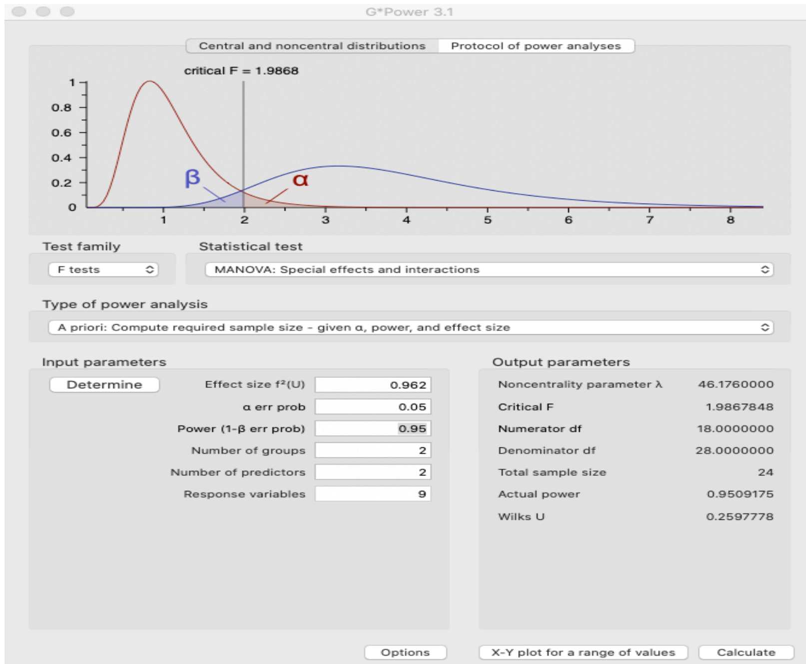
Thank you for your time and for participating,

Brian

Brian Teske
PhD Candidate
Aerospace Sciences
University of North Dakota
952 221 139

Appendix E

G*Power Analysis



Appendix F

Organizational Safety Attribute Awareness Survey

ORGANIZATIONAL SAFETY ATTRIBUTES AWARENESS SURVEY 1 and 2

D1 Years of experience in your industry

- o 0 to 5 years
- o 5 to 10 years
- o 10 to 15 years
- o Over 15 years

D2 Your primary role in the organization

- o Nonsupervisor (operations, support, administrative, staff, ...)
- o First-level supervisor (responsible for a small group)
- o Manager (manages at least one subordinate level of managers)
- o Senior Manager (responsible for controlling and overseeing the organization)

PF1 The organization has a good roadmap of each other’s talents and skills

- o Strongly disagree
- o Disagree
- o Somewhat disagree
- o Neither agree nor disagree
- o Somewhat agree
- o Agree
- o Strongly agree

PF2 We spend time identifying activities we do not want to go wrong

- o Strongly disagree
- o Disagree

- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Agree
- Strongly agree

RS1 We discuss alternatives as to how to go about our normal work activities

- Strongly disagree
- Disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Agree
- Strongly agree

SO2 We have a good "map" of each person's talents and skills

- Strongly disagree
- Disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Agree
- Strongly agree

SO2 We discuss our unique skills with each other so that we know who has relevant specialized skills and knowledge

- Strongly disagree
- Disagree

- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Agree
- Strongly agree

CR1 We talk about mistakes and ways to learn from them

- Strongly disagree
- Disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Agree
- Strongly agree

CR2 When errors happen, we discuss how we could have prevented them

- Strongly disagree
- Disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Agree
- Strongly agree

DE1 When attempting to resolve a problem, we take advantage of the unique skills of our colleagues

- Strongly disagree
- Disagree

- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Agree
- Strongly agree

DE2 When a crisis occurs, we rapidly pool our collective expertise to attempt to resolve it

- Strongly disagree
- Disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Agree
- Strongly agree

P2 There is a top-level management person who is ultimately responsible and accountable for safety and has the necessary authority over all resources to make risk-based decisions related to the organization’s activities (accountable executive).

- Strongly disagree
- Disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Agree
- Strongly agree

P3 There is a qualified and well-trained safety professional who manages the organization’s safety program coordinates the system safety processes, and has direct reporting to the accountable executive.

- o Strongly disagree
- o Disagree
- o Somewhat disagree
- o Neither agree nor disagree
- o Somewhat agree
- o Agree
- o Strongly agree

P5 Procedures in the safety plan are documented, communicated, and implemented in the organization.

- o Strongly disagree
- o Disagree
- o Somewhat disagree
- o Neither agree nor disagree
- o Somewhat agree
- o Agree
- o Strongly agree

P5.1 Processes in the safety plan are documented and known throughout the organization.

- o Strongly disagree
- o Disagree
- o Somewhat disagree
- o Neither agree nor disagree
- o Somewhat agree
- o Agree
- o Strongly agree

P6 Procedures exist within the organization to manage and respond to adverse safety events such as accidents, incidents, and operational emergencies.

- o Strongly disagree
- o Disagree
- o Somewhat disagree
- o Neither agree nor disagree
- o Somewhat agree
- o Agree
- o Strongly agree

SP8 There are documented and clearly defined expectations of safety accountability for all personnel at every level within the organization.

- o Strongly disagree
- o Disagree
- o Somewhat disagree
- o Neither agree nor disagree
- o Somewhat agree
- o Agree
- o Strongly agree

SRM1 Processes are clearly defined to ensure that activities or conditions that can result in death, injuries, equipment damage, or adverse operational outputs are identified and documented.

- o Strongly disagree
- o Disagree
- o Somewhat disagree
- o Neither agree nor disagree
- o Somewhat agree
- o Agree

- o Strongly agree

SRM2 Processes are clearly defined to ensure a safety risk assessment is accomplished for all identified hazards.

- o Strongly disagree
- o Disagree
- o Somewhat disagree
- o Neither agree nor disagree
- o Somewhat agree
- o Agree
- o Strongly agree

SRM3 Processes are defined to ensure that safety controls are applied to mitigate identified risks to the lowest acceptable level.

- o Strongly disagree
- o Disagree
- o Somewhat disagree
- o Neither agree nor disagree
- o Somewhat agree
- o Agree
- o Strongly agree

SRM4 Effective controls are applied to those risks that are classified as unacceptable as part of hazard identification and risk mitigation in the organization.

- o Strongly disagree
- o Disagree
- o Somewhat disagree
- o Neither agree nor disagree
- o Somewhat agree

- Agree
- Strongly agree

SRM5 A non-punitive (may be anonymous) reporting system for safety issues is established and available for all employees.

- Strongly disagree
- Disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Agree
- Strongly agree

SA1 The organization has an effective and documented system to measure the effectiveness of risk controls and safety performance.

- Strongly disagree
- Disagree
- Somewhat disagree
- Neither agree nor disagree
- Somewhat agree
- Agree
- Strongly agree

SA2 Clear evidence exists showing the organization continuously monitors operational data to determine and document compliance to established risk controls (Data includes products and services received from contractors, safety reports, and employee safety feedback).

- Strongly disagree
- Disagree
- Somewhat disagree

- o Neither agree nor disagree
- o Somewhat agree
- o Agree
- o Strongly agree

SA3 Clear evidence exists showing clear, relevant system safety outputs are generated regularly, thoroughly reviewed, and incorporated into policies, procedures, and processes by top management.

- o Strongly disagree
- o Disagree
- o Somewhat disagree
- o Neither agree nor disagree
- o Somewhat agree
- o Agree
- o Strongly agree

SA6 Clear evidence exists showing auditors possess appropriate professional qualifications and are independent of any processes or work evaluated.

- o Strongly disagree
- o Disagree
- o Somewhat disagree
- o Neither agree nor disagree
- o Somewhat agree
- o Agree
- o Strongly agree

SA7 Clear evidence exists showing that procedures are clearly defined, documented, communicated, and implemented to collect safety data (including investigating incidents and accidents).

- o Strongly disagree

- o Disagree
- o Somewhat disagree
- o Neither agree nor disagree
- o Somewhat agree
- o Agree
- o Strongly agree

SA7.1 Clear evidence exists showing that procedures are clearly defined, documented, and communicated to collect instances of regulatory non-compliance, and to identify potential new hazards or risk-control failures.

- o Strongly disagree
- o Disagree
- o Somewhat disagree
- o Neither agree nor disagree
- o Somewhat agree
- o Agree
- o Strongly agree

SA8 Clear evidence exists that shows a process for proactive hazard identification.

- o Strongly disagree
- o Disagree
- o Somewhat disagree
- o Neither agree nor disagree
- o Somewhat agree
- o Agree
- o Strongly agree

SA9 Clear evidence exists that shows a process for predictive hazard identification.

- o Strongly disagree

- o Disagree
- o Somewhat disagree
- o Neither agree nor disagree
- o Somewhat agree
- o Agree
- o Strongly agree

SP1 Senior management's commitment to safety, which includes sustaining a positive safety culture, is recognized by all personnel and documented.

- o Strongly disagree
- o Disagree
- o Somewhat disagree
- o Neither agree nor disagree
- o Somewhat agree
- o Agree
- o Strongly agree

SP2.2 Clear documentation exists that defines the safety training processes in place to ensure that all personnel are properly trained.

- o Strongly disagree
- o Disagree
- o Somewhat disagree
- o Neither agree nor disagree
- o Somewhat agree
- o Agree
- o Strongly agree

SP3 Clear documentation exists, demonstrating that all personnel are appropriately well trained to perform their duties related to the safety system. (This includes the scope of training with required competencies and responsibilities in the safety system. Additionally, initial and periodic safety system training for all employees is clearly outlined, scheduled, and performed).

- o Strongly disagree
- o Disagree
- o Somewhat disagree
- o Neither agree nor disagree
- o Somewhat agree
- o Agree
- o Strongly agree

SP5 Clear evidence exists demonstrating an appropriate safety system recurrent training is completed for all employees.

- o Strongly disagree
- o Disagree
- o Somewhat disagree
- o Neither agree nor disagree
- o Somewhat agree
- o Agree
- o Strongly agree

SP6 Clear documentation exists that lists the communications of safety system outputs throughout the organization, the rationale behind controls, and preventative or corrective actions, including oversight information.

- o Strongly disagree
- o Disagree
- o Somewhat disagree
- o Neither agree nor disagree
- o Somewhat agree

- o Agree
- o Strongly agree

Appendix G

Agreement to Use the Stolzer et al. (2018) Journal Article

ELSEVIER LICENSE
TERMS AND CONDITIONS

Apr 16, 2020

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Licensed Content Title	Measuring and evaluating safety management system effectiveness using Data Envelopment Analysis
Licensed Content Author	Alan J. Stolzer,Mark A. Friend,Dothang Truong,William A. Tuccio,Marisa Aguiar
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Circulation	100
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Title	Preparing Commercial Space Organizations for Safety Management System Implementation
Institution name	Brian Teske
Expected presentation date	Dec 2021
Order reference number	TESKE Stolzer 2018
Requestor Location	Brian Teske 3505 W 28th Street

Appendix H

Agreement to Use Vogus and Sutcliffe (2007) Survey Questions

WOLTERS KLUWER HEALTH, INC. LICENSE TERMS AND CONDITIONS

May 04, 2020

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All payments must be made in full to CCC. For payment instructions, please see information listed at the bottom of this form.

License Number	4821990399576
License date	May 04, 2020
Licensed Content Publisher	Wolters Kluwer Health, Inc.
Licensed Content Publication	Medical Care
Licensed Content Title	The Safety Organizing Scale: Development and Validation of a Behavioral Measure of Safety Culture in Hospital Nursing Units
Licensed Content Author	Timothy Vogus and Kathleen Sutcliffe
Licensed Content Date	Jan 1, 2007
Licensed Content Volume	45
Licensed Content Issue	1
Type of Use	Manner not listed
Requestor type	University/College
Sponsorship	No Sponsorship
Format	Electronic
Portion	Figures/tables/illustrations
Number of figures/tables/illustrations	1
Author of this Wolters Kluwer article	No
Will you be translating?	No
Intend to modify/adapt the content	Yes
Special Requirements	The Safety Organizing Survey questions (9 in total) will be used for HRT research in the commercial space industry in a survey format. 2 questions will need to be modified. 150 people will participate in an electronic format.
Order reference number	Teske SOS figure
Portions	Safety Organizing Survey questions
Additional Information	2 will be modified.

Appendix I

Max Likelihood Estimates Results for the SMS Variables

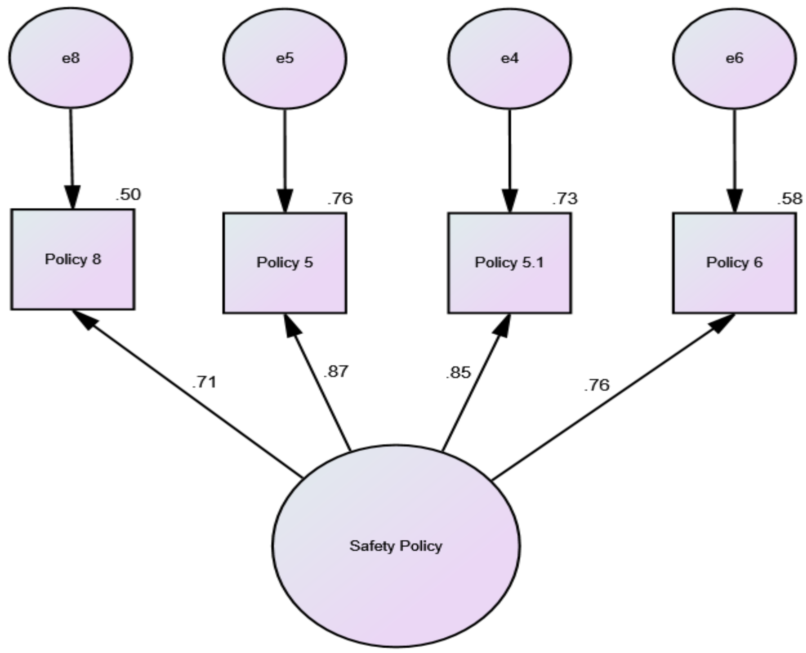

Figure I1. Confirmatory factor analysis factor loading for safety policy.

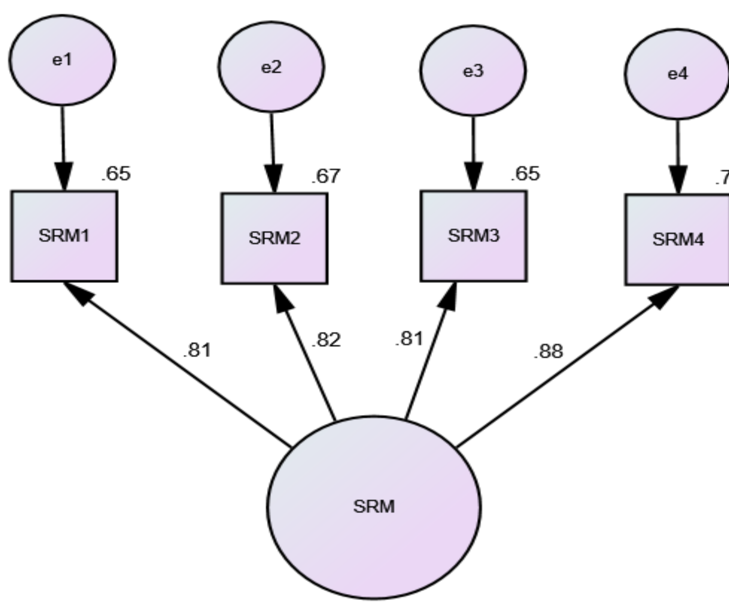

Figure I2. Confirmatory factor analysis factor loading for safety-risk management.

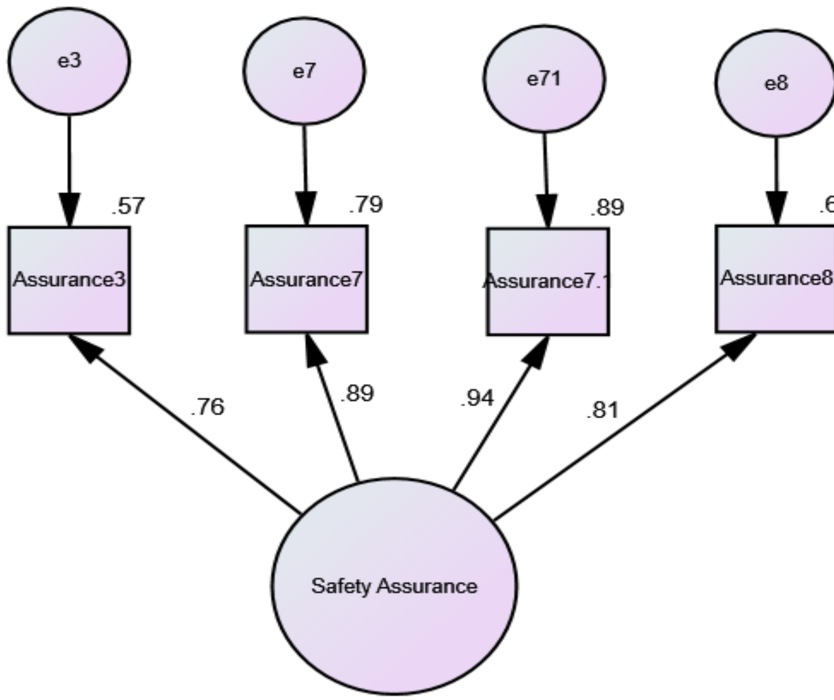

Figure I3. Confirmatory factor analysis factor loading for safety assurance.

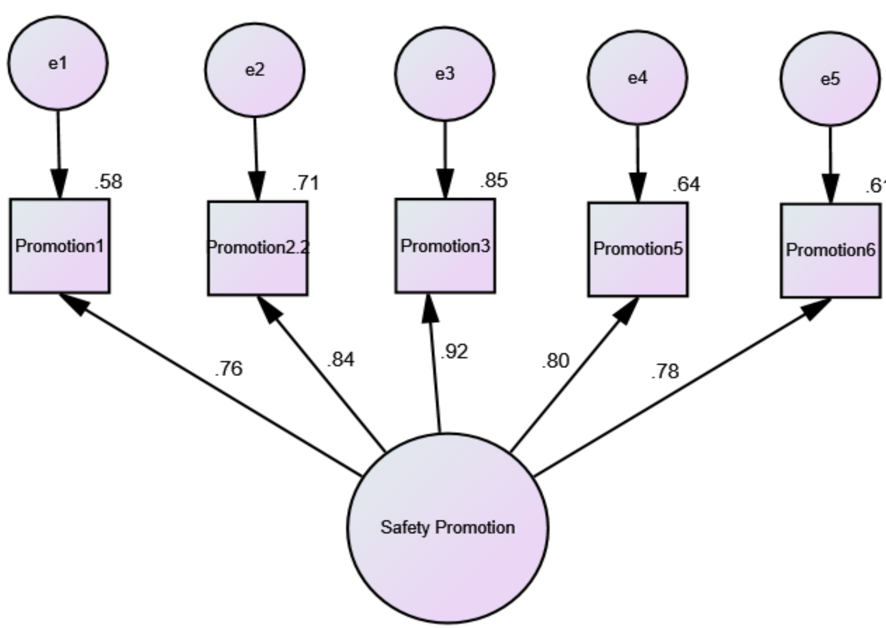

Figure I4. Confirmatory factor analysis factor loading for safety promotion.

Appendix J

Question 2 *t*-Test

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Policy mean	Equal variances assumed	0.750	0.388	2.645	145	0.009	0.31016	0.11725	0.07842	0.54189
	Equal variances not assumed			2.540	106.877	0.013	0.31016	0.12209	0.06813	0.55218
SRM mean	Equal variances assumed	0.022	0.882	1.566	145	0.120	0.20503	0.13094	-0.05378	0.46383
	Equal variances not assumed			1.573	126.384	0.118	0.20503	0.13037	-0.05297	0.46302
Assurance mean	Equal variances assumed	2.258	0.135	3.907	145	0.000	0.58503	0.14974	0.28909	0.88098
	Equal variances not assumed			3.701	101.096	0.000	0.58503	0.15807	0.27146	0.89860
Promotion mean	Equal variances assumed	0.982	0.323	0.851	145	0.396	0.13349	0.15685	-0.17651	0.44350
	Equal variances not assumed			.819	107.964	0.414	0.13349	0.16291	-0.18942	0.45640

Appendix K

Question 3 *t*-Test

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Preoccupation	Equal variances assumed	6.272	.013	3.648	151	.000	.64995	.17815	.29795	1.00194
	Equal variances not assumed			3.487	109.868	.001	.64995	.18641	.28052	1.01938
Reluctance	Equal variances assumed	5.214	.024	3.365	151	.001	.697	.207	.288	1.106
	Equal variances not assumed			3.222	110.751	.002	.697	.216	.268	1.125
Sensitivity	Equal variances assumed	4.553	.034	2.296	151	.023	.50443	.21966	.07042	.93844
	Equal variances not assumed			2.214	113.875	.029	.50443	.22787	.05301	.95585
Resilience	Equal variances assumed	.070	.792	1.036	151	.302	.16838	.16248	-.15264	.48940
	Equal variances not assumed			1.056	139.439	.293	.16838	.15938	-.14674	.48350
Expertise	Equal variances assumed	2.553	.112	1.219	151	.225	.22882	.18775	-.14214	.59978
	Equal variances not assumed			1.184	117.686	.239	.22882	.19320	-.15379	.61143

REFERENCES

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